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COMPLETION OF SYSTEMS DEVELOPMENT AND ADAPTATION PHASE OF CANMET DIESEL EMISSIONS REDUCTION PROGRAM - PART III.

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TABLE OF CONTENTS

		Page No.
1.	INTRODUCTION.....	1
2.	DYNAMIC DYNAMOMETER TEST CELL	2
	2.1 Dynamometer.....	2
	2.2 Computer Control System	2
3.	HEAVY DUTY DIESEL EMISSIONS TEST FACILITY...	3
	3.1 Dilution Tunnel System	3
	3.1.1 Dilution Tunnel	3
	3.1.2 Heat Exchanger	4
	3.1.3 Air Mover	5
	3.2 Gas Analysis	5
	3.3 Ames Mutagenicity Assay Procedure	6
	3.4 PAH Sampling and Analytical Procedure..	6
	3.5 Sulphate Sampling and Analysis	7
4.	TASK 1 - Facility Preparation	7
5.	TASK 2 - Assessment of Manganese Removal by Diesel Particulate Filter	8
	5.1 Sampling Methodology	8
	5.2 Analytical Methodology	9
	5.3 Test Engine and Fuel Additive	9
	5.4 Test/Sample Sequence	10
	5.5 Results	10
6.	TASK 3 - Degussa Catalyzed DPF Evaluation..	12
	6.1 MTU Cycles - Modifications and Analysis	13
	6.2 Test Conditions	14
	6.3 Ignition Temperature Tests.....	14
	6.4 Durability	15
	6.5 Gaseous Emissions	15
	6.6 Particulate and Sulphur Emissions	16
	6.7 Ames Mutagenicity Assay	17
	6.8 Polynuclear Aromatic Hydrocarbons.....	17

LIST OF TABLES

TABLE 1 Manganese Fuel Concentrations Comparison

TABLE 2 Oil and Fuel Manganese Concentrations

TABLE 3 DPF Manganese Filtration Efficiency

TABLE 4 Exhaust Gas Manganese Concentrations

TABLE 5 Analysis of MTU LHD Cycle

TABLE 6 Analysis of MTU MOD 5 LHD Cycle

TABLE 7 Durability Tests - Average Engine Conditions

TABLE 8 Gaseous Mass Emissions - MTU MOD 5 Cycle

TABLE 9 Oxides of Nitrogen Steady-State Comparison

TABLE 10 Total Particulate Emissions

TABLE 11 Polynuclear Aromatic Hydrocarbons.

LIST OF FIGURES

FIGURE 1 Flow Diagram for Heavy Duty Diesel Exhaust Sampling.

FIGURE 2 Sulphate Sampling Train Schematic.

FIGURE 3 Modified EPA #5 Sample Train.

FIGURE 4 MTU MOD 4 LHD Cycle Torque vs. Time.

FIGURE 5 MTU MOD 4 LHD Cycle Speed vs. Time.

FIGURE 6 MTU MOD 4 LHD Cycle Torque vs. Time.

FIGURE 7 MTU MOD 5 LHD Cycle Speed vs. Time.

FIGURE 8 Ignition Temperature #1 Base Metal DPFs.

FIGURE 9 Ignition Temperature #2 Base Metal DPFs.

FIGURE 10 Ignition Temperature #3 Base Metal DPFs.

FIGURE 11 Ignition Temperature #1 Base/Precious Metal DPF.

FIGURE 12 Ignition Temperature #1 Base/Precious Metal DPF.

FIGURE 13 Ignition Temperature #2 Base/Precious Metal DPF.

FIGURE 14 Durability - Base Metal DPFs.

FIGURE 15 Durability - Base/Precious DPFs.

FIGURE 16 Durability - Base Metal Comparison.

FIGURE 17 Durability - Base/Precious Comparison.

FIGURE 18 Torque (MTU Cycle) - Reference vs. Actual.

FIGURE 19 Speed " "

FIGURE 20 Power " "

FIGURE 21 MTU LHD Cycle - Torque vs. Time.

FIGURE 22 MTU LHD Cycle - Speed vs. Time.

ORI

LIST OF FIGURES (Cont'd.)

FIGURE 23 MTU LHD Cycle - Torque vs. Time 0- 50 sec.
FIGURE 24 MTU LHD Cycle - Torque vs. Time. 50-100 sec.
FIGURE 25 " " 100-150 secs.
FIGURE 26 MTU LHD Cycle Speed vs. Time 0 - 50 secs.
FIGURE 27 " " 50 - 100 secs.
FIGURE 28 " " 100 - 150 secs.
FIGURE 29 Torque (MTU MOD 5 LHD Cycle) Reference vs. Actual.
FIGURE 30 Speed " "
FIGURE 31 Power " "
FIGURE 32 MTU MOD 5 LHD Cycle - Torque vs. Time 0- 50 secs.
FIGURE 33 " " 50-100 secs.
FIGURE 34 " " 100-150 secs.
FIGURE 35 MTU MOD 5 LHD Cycle - Speed vs. Time 0- 50 secs.
FIGURE 36 " " 50-100 secs.
FIGURE 37 " " 100-150 secs.

LIST OF APPENDICES

APPENDIX I Fuel Additive Safety Data Sheets.
APPENDIX II Cycle Analyses.

1. INTRODUCTION

This report covers the final laboratory phase of the collaborative USBM/CANMET/MOL research and development program leading to underground environmental impact trials on two LHD machines. These machines, being a Wagner ST5 scooptram and a Jarvis Clark JS500 LHD vehicle.

Emission control systems based on ceramic diesel particulate filters (DPFs) have reached the stage of development for practical field evaluations. Work with fuel additives and catalyzed DPFs has shown that DPFs can be regenerated under many field conditions. However, there are environmental concerns with both these methods, which have been addressed by this program.

Fuel additives containing manganese and manganese/copper have been used to lower regeneration temperatures to as low as 350°C. Unaided regeneration of diesel particulate material on a ceramic DPF takes place at approximately 500°C. Copper is in question because of the potential negative effects of deposits on engine components.

Recent controversy over the TLV (Threshold Limit Value) of manganese, has prompted studies on the amount of manganese passing through DPFs. The accepted TLV for manganese has been 1 mg Mn/m^3 in the ambient air. Recent investigations have suggested the TLV be lowered to 1 ug Mn/m^3. Preliminary studies by Volkswagen in Germany have suggested 85% retention of manganese by DPFs. The purpose of this CANMET program was to confirm that DPFs are efficient in removing manganese additives from the exhaust.

Previous work with precious metal catalyzed ceramic DPFs have shown reduction in regeneration temperatures to 375°C. However, these precious metal formulations convert a significant portion of the exhaust SO_2 to H_2SO_4, depending on the exhaust gas temperature. The simplicity of using catalyzed DPFs (i.e. no additional regeneration equipment required) makes their use very desirable from a practical point of view. Therefore, this program evaluated two alternative catalytic formulations supplied by Degussa USA. These formulations were developed to obtain the best combination of low regeneration temperatures and low SO_2 to H_2SO_4 conversion.

Task 4 of this program was for ORF to consult with, and give assistance to, Jarvis Clark, in preparing and installing two emission control systems on a Jarvis Clark LHD vehicle. The systems to be evaluated were an EGR/DPF combination and the Venturi water scrubber. This task was deleted from the program by CANMET but provision was made for travel and living charge for consultation with Jarvis Clark.

Under these provisions, ORF staff visited Michigan Technological University to discuss the vehicle outfitting and evaluation. In May of 1985, ORF staff delivered the Venturi scrubber system, EGR equipment and a Deutz F8L-413 FW Engine (S/N 628399) to Jarvis Clark in Burlington. In June, ORF and CANMET met at Jarvis Clark and finalized the system installation details. During July, Jarvis Clark completed the engine and emission control system installation and shipped the LHD vehicle to MTU.

2. DYNAMIC DYNAMOMETER TEST CELL

The following sub-sections describe some of the test equipment used in this study.

2.1 Dynamometer

An Eaton Model AO-8121 Eddy current dynamometer is used to absorb the power generated by the engine. This dyno is a wet gap type capable of absorbing 373 kW at 5000 RPM and has an inertia of 46 lb. ft^2. Torque is measured using a Lebow load cell connected to the trunnion mounted dynamometer casing. The dynamometer operation can be manually controlled in a speed or torque mode via a stand-alone dyno excitation controller. Dynamometer bearing lubrication is provided by gravity fed oil reservoirs. A Hayes-Dana driveshaft with rubber element absorption is used as a coupling between the engine and dyno.

2.2 Computer Control System

The heart of the dynamic test facility lies in the computer control system. This system uses a Hewlett Packard 1000 series E computer with 128K of memory and is coupled with an HP disc drive unit. Input/output interface is performed with Computer Products I/O equipment.

All programs are stored on an HP 7900 disc unit with measured and calculated data displayed on the operator console. The console is also used for entering operation commands concerning the test cell. During automatic control, the system reads engine speed and torque ten times per second and, if required, corrects via output signals, ten times per second. The system has a programming capability for cycle testing known as the schedule builder. The schedule builder is based upon a series of steps. A step is a defined RPM, torque, ramp time, stay time, where ramp time is the length of time to change from one load speed condition to the next. Stay time is defined as the length of time to remain at a given load speed. The minimum ramp time is one second and the minimum stay time is zero seconds. Up to 198 steps are user definable, however, the system includes the capability of major and minor looping within a cycle.

3. HEAVY DUTY DIESEL EMISSIONS TEST FACILITY

The sampling and measurement of diesel exhaust emissions has presented many problems with respect to obtaining representative data that will correlate to conditions that occur in the underground mining environment. Chemical and physical reactions with certain species of diesel exhaust emissions take place after the exhaust has been released from the engine exhaust system. Specifically, particulate agglomeration in the soluble and insoluble form, occur as the exhaust temperature is lowered to promote condensation of the soluble organic material. Formation of nitrogen dioxide (NO_2) from nitric acid (NO) is a characteristic reaction in diesel exhaust. These reactions have necessitated the need for a representative diesel exhaust sampling and analysis system. EPA has standardized such a system for engine certification procedures.

In an effort to keep abreast of these changes, ORF has installed and commissioned a heavy duty diesel emissions test facility (see Figure 1). The primary purpose of this facility is the measurement of emissions from diesel engines which are part of the dynamic test facility. The facility is comprised of two major systems; the dilution tunnel system and the analytical system. The following sub-sections describe these systems.

3.1 Dilution Tunnel System

There are basically two types of dilution tunnels available for the sampling of diesel exhaust emissions. One uses a single dilution method, the other a double dilution. ORF has selected a double dilution tunnel from a flexibility and cost standpoint. With a double dilution system, the primary air mover can be down-sized considerably to meet the temperature criteria necessary in designing such a system. The system is comprised of three basic sections as described below.

3.1.1 Dilution Tunnel

The dilution tunnel consists of 25.4 cm inside diameter primary tunnel and a 10.2 cm inside diameter secondary tunnel. All tunnel components fabricated of stainless steel. Engine exhaust enters the primary tunnel via an upstream facing 10.2 cm nozzle. Dilution air flows past the nozzle and the resultant counter-current flow enhances mixing of the exhaust with the air. The primary tunnel has been engineered to provide a Reynolds number of more than 4000 to provide sufficient turbulence of the diluted exhaust. A fine mesh screen prevents large foreign objects from entering the primary tunnel.

Three sample probes are located approximately 2.5 meters downstream of the exhaust inlet. The first probe is used to transfer a portion of the primary tunnel exhaust to the

secondary tunnel. The second probe is used for sample transport to the heated hydrocarbon analyzer and the third probe is dedicated to the other gaseous analyzers. Maximum allowable primary tunnel gas temperature at the sample probes is 190°C. A specially designed acoustic chamber was installed at the primary tunnel inlet to minimize engine exhaust and air mover noise in the vicinity of the test facility.

The secondary tunnel can be used to further dilute the sample from the primary tunnel to maintain a sample filter that will not exceed the maximum allowable 52°C. Three sample filters and one bypass filter are connected to the outlet of the secondary tunnel. The filter holders accept 70 mm diameter filters (Pallflex T60A20) and produce a 60 mm diameter stain area.

Secondary, or back-up filters, are used to remove any particulate material that has passed the primary filter. Any one of the four filters can be selected manually or automatically from the particulate console. Automatic sequencing of the filter is achieved using computer activated relays or using a programmable sequence timer.

The particulate console contains an air pump and protective filters for sampling diluted exhaust. A second pump is used to provide pre-filtered air to the secondary tunnel when further dilution is required. Mass flows of sample gas and secondary dilution air are measured and controlled using mass flow controllers (Tylan Model FC202). These controllers are state-of-the-art devices which continuously monitor and correct the mass flow to maintain a proportional sampling rate, regardless of gas temperature and pressure. Accumulated dilution and sample gas flows are displayed using integrators, one set for each of the sample filters. The particulate console also contains a temperature measuring device to allow for recording of a variety of temperature stations, especially the primary and secondary tunnel gas temperatures.

3.1.2 Heat Exchanger

According to EPA specifications, the primary tunnel gas temperature must be adjusted to 43°C in order to provide constant gas density conditions to the primary air mover. In order to achieve a 147°C gas temperature drop, a tube and shell heat exchanger is located between the primary dilution tunnel and air mover. A 117 l pm water pump recirculates water through the shell side of the heat exchanger while primary tunnel exhaust gas is passed through the tube side.

During testing of duty cycles with high load factors, the

primary tunnel gas temperature is well above 43°C. In these cases, the exchanger is used solely to cool the gas and this is achieved by adding cold water to the recirculating water loop. Thermostatically controlled, air actuated, water valves allow water to enter the system and a check valve discharges an equal volume of warm water. A second heat exchanger which is steam heated can be used to raise the water temperature to 43°C (in the case of low load factor duty cycles).

3.1.3 Air Mover

The primary tunnel gas flow is normally maintained at 51.0 standard cubic meters per minute (SCMM) with a high capacity positive displacement blower. This blower is a roots type and uses a 22 kW electric motor as a drive. Excessive noise characteristics of these blowers is reduced using a Donaldson muffler.

3.2 Gas Analysis

The gas analysis system is comprised of a hydrocarbon console and a main analysis console. Filters, housed in the heated hydrocarbon console, are used to remove particulate matter from the sample gas stream. A Beckman, Model 402, heated hydrocarbon analyzer continuously measures gaseous hydrocarbons (as methane) at a temperature of 190°C using a flame ionization detector. Background (ambient air) hydrocarbon concentrations are determined by sampling the dilution air at the primary tunnel. Concentrations of hydrocarbons in the dilution air are subtracted from the primary tunnel concentration to obtain hydrocarbon concentrations that are attributable to engine exhaust.

The main analysis console contains the NO, CO, CO_2 and heated NO_x analyzers. Four sample pumps are used to provide sample gas to the various analyzers. The following analyzers are used:

NO_x	-	Beckman Model 955 heated chemiluminescent analyzer
NO	-	Beckman Model 951A chemiluminescent analyzer
CO	-	Beckman Model 867 non-dispersive infra-red
CO_2	-	Beckman Model 864 non-dispersive infra-red
CO_2	-	Horiba Model AIA-21-AS non-dispersive infra-red.

Three calibration gases are used to span each analyzer for a given concentration range. These gases can be selected by push buttons on the main analysis console front panel. Heated lines are used to keep the sample temperature well above the gas dew-point to minimize losses due to condensation. A Hankinson dryer is used to remove sample gas moisture prior to the NO, CO analyzers. Air/water heat exchangers are used to remove sample gas moisture prior to the CO_2 analyzers.

ORI

Recent additions to the HP 1000 computer software now provide the capability of recording all gaseous emissions data for steady state and cycle testing. The computer provides a printout of gaseous pollutant mass emissions and exhaust flows and can average results over a transient engine operating cycle.

3.3 Ames Mutagenicity Sampling and Assay Procedure

Sampling is conducted by diverting a portion of the diesel exhaust through a heated sampling probe into a dilution tube. A calibrated high volume sampler is used as a primary air mover. The diesel engine exhaust sample mixes with the dilution air and is passed through a 25 x 20 cm teflon coated glass fibre filter. Dilution ratios of approximately 16:1 are achieved by controlling the sample air mover speed.

The Salmonella tester strain used for the treated exhaust and baseline tests was TA-98, in absence of metabolic activation. Filters were extracted for 16 hours with dichloromethane.

The solvent extract was then taken to dryness and the weight of the soluble organic fraction (SOF) determined. Samples were then dissolved in dimethysulfur/oxide (DMSO) to concentration of 2000 ug/mL and tested in the Ames assay. Testing was carried out between 0 and 1000 ug/plate to obtain dose-response data. The specific activity as revertant/ug was calculated from the linear position of the dose response curve.

3.4 PAH Sampling and Analytical Procedure.

The sampling procedure is similar to that used for collecting samples for the Ames Bioassay. The diesel engine exhaust sample mixes with the dilution air and is passed through a 25 x 20 cm teflon coated glass fibre filter followed by two Polyurethane Foam filters (PUFs). The PUFs assist in the capture of the more volatile PAHs which may pass through the filter. Dilution ratios of approximately 16:1 are achieved by controlling the sample air mover speed.

The PUFs were cleaned prior to sampling by Soxhlet extraction with cyclohexane. Following sampling, the PUFs were cut into small pieces and extracted in a Soxhlet apparatus for 8 hours with cyclohexane. Hi-Vol filters were extracted for 12 hours with cyclohexane in a Soxhlet apparatus and the extracts evaporated to dryness on a rotary evaporator under reduced pressure at 35^{o}C. The extract residue was then dissolved in 5 to 10 mL of methanol.

The sample was injected into a high performance liquid chromatograph for the quantitative determination of the following PAH compounds:

ORI

- o fluoranthene (F)
- o benzo[a]anthracene (B[a]A)
- o benzo[k]fluoranthene (B[k]F)
- o benzo[a]pyrene (B[a]P)
- o dibenzo[ah]anthracene (DiBenz[ah]A)
- o benz[ghi]perylene (Benz[ghi]Per).

3.5 Sulfates Sampling and Analysis

Tests were conducted using the controlled condensation sampling system. This system, illustrated in Figure 2, allows for the quantitative collection of sulfates ($SO_4^=$) and sulfur dioxide (SO_2) from hot exhaust gas streams. The sampling system withdraws diluted exhaust gas (11 L/min) through a glass probe maintained at 250°C, followed by a glass cooling coil, maintained at 70°C. The sulfate fraction is removed in the coil while sulfur dioxide is removed in a set of impingers, downstream of the coil. Impingers contain a 3% (v/v) hydrogen peroxide solution. Solutions are subsequently analyzed using a spectrophotometer to determine the sulfur concentrations.

4. TASK 1 - FACILITY PREPARATION

Before beginning the test program, the facilities were prepared by checking, repairing and altering the engine test cell, engine, exhaust systems and dilution tunnel/emissions bench. The following list details the preparations that were required.

1. Engine
   - basic maintenance performed, such as lube, oil and filter;
   - timing checked;
   - checked engine performance by performing a torque curve;
   - exhaust system repaired;
   - thermocouples replaced, as required.
2. Test Cell
   - calibration and operation of dynamometer, fuel meter and pressure transducers checked;
   - checked condition of fuel lines, pressure lines, thermocouples;
   - checked and made repairs on engine/cell cooling air systems.

ORI

3. Dilution Tunnel/Emissions Bench.

- checked condition of heat exchanger;
- checked and replaced filters in emissions test bench;
- checked all sample lines for leaks and heating;
- ensured all analyzers working properly;
- checked calibration of dry gas meters.

4. General - ordered filters, chemicals, fuel, oil, etc. that were required for the test program.

5. TASK 2 - ASSESSMENT OF MANGANESE REMOVAL BY DPFS

Metal analysis in diesel exhaust was a new test procedure in the Centre for Alternative Fuel Utilization at ORF. However, the Stack Sampling Group had performed similar tests on stack gases. Therefore, the first portion of this task involved discussions with ORF stack sampling specialists and analytical chemistry staff. From these discussions, sampling and analytical procedures were developed based on the expertise of these groups.

5.1 Sampling Methodology

A modified EPA #5 sample train was used to collect the exhaust gas samples. Before assembling the train, all glassware was soaked in 20% HNO_3 and rinsed with 5% HNO_3. Polyethylene sample bottles and the filter frit were cleaned and rinsed with 5% HNO_3. The sample train set-up is shown Figure 3. Exhaust gases were drawn from the dilution tunnel at 22L/min. through a glass probe heated to 100°C. Sample gases were then drawn through a 125 mm teflon-coated glass fibre filter and four glass impingers. The first two impingers contained 125 ml each of 5% nitric acid, the third was empty and the fourth contained activated silica gel desiccant. A compressor and dry gas meter completed the sample train.

Once the sample had been obtained, the glass probe and impingers were rinsed with 5% nitric acid and combined. Each test had a filter and an impinger/probe solution to be analyzed.

Lubrication oil samples were taken from the oil sump. Fuel samples were taken from the 45 gallon drums on the day of testing in case any settling of the additive took place.

5.2 Analytical Methodology

Impinger solutions were analyzed without further treatment, by DC plasma emission spectrophotometry (DCPE). This method has a detection limit of .02 µg/ml of manganese (Mn) or iron (Fe). One quarter of each filter was taken and treated twice with concentrated aqua regia. The solubles were then diluted to volume and analyzed by DCPE. The detection method for this procedure was 2 µg Mn per filter.

An aliquot of each oil sample was ashed. The ashes were dissolved in concentrated aqua regia, diluted to volume and analyzed by DCPE.

The baseline diesel fuel, diesel fuel additive mixtures, and the additive itself, were analyzed using some variations of a flame atomic absorption method. In the first method, aliquots of the samples were diluted with methylisobutylketone (MIBK) and analyzed by background-corrected flame atomic absorption spectrophotometry. Conostan-21 (an oil-base organometallic standard) diluted in MIBK, was used for calibration. The atomic resonance line at 279.5 nm was used. The results from this procedure were significantly lower than expected for the fuel/additive mixtures. After some discussion between ORF and Lubrizol (the additive manufacturer), the tests were repeated using kerosene for dilution rather than MIBK. Lubrizol also analyzed the same samples as a check. It was concluded that there was some sample or standard instability in the MIBK but that kerosene gave the correct results.

5.3 Test Engine and Fuel Additive

A Deutz F8L-413 FW naturally aspirated diesel engine was used for the entire CANMET program. This engine had been used previously in testing with both manganese and copper/manganese fuel additives.

The fuel additive used was supplied by Lubrizol Corporation. This manganese-based additive was identified as 8220 and contained 40 mg of manganese per millilitre of stock additives. A nominal treatment level of 80 mg Mn per litre of fuel was used. The appropriate amount of fuel additive was thoroughly mixed with diesel fuel in a 200 litre drum, on the same day as the test. This procedure minimizes the risk of fuel additive settling or coagulating.

ORF

5.4 Test Sequence - Samples Taken

Test	Exhaust Samples	Oil Samples	Fuel Samples
1	- blank filter - probe/impinger Proving rinse	- new oil - engine lube oil before changed.	- neat diesel fuel - fuel additive
2	- baseline (stock engine)	- engine lube oil after change.	
3		- engine lube oil after baseline.	
4	- stock engine		- diesel fuel plus additive.
5		- engine lube after 24 hours.	
6	- DPFs + fuel additives		- diesel fuel additives.
7		- engine lube oil after test completion.	

5.5 Test Results

Since the mixing of the fuel additive and fuel in the drum was only approximate, analyses were performed on the actual fuel mixtures used. An additive concentration of 80 µg Mn/L fuel was the target. As explained in the methodology above, the first analyses were unexpectedly low, but after consultation and sample checks with Lubrizol (the additive manufacturer) the correct results were determined as shown following.

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TABLE 1 - Manganese Fuel Concentrations Comparison (mg Mn/L fuel)

Sample	Initial ORF	Lubrizol	Final ORF
Baseline Fuel	~ 1.3	0	< 0.3
Fuel + Additive (No DPFs)	53.8	71.4	71.3
Fuel + Additive	53.3	66.3	67.5

This table shows the actual fuel manganese concentrations used during the program.

It was suspected that some of the fuel manganese may work its way into the lubrication oil. Therefore, oil samples were taken from the engine oil sump at various times during the program. All oil samples were taken after warming up the engine, to ensure the lube oil and any additive present would be completely mixed. From the results shown in Table 2, the total manganese present in the lube oil was estimated. From the fuel manganese concentrations and the fuel consumptions, the total manganese used by the engine was determined.

The total gain in oil manganese during 7.0 hours of additive testing, was 386 mg. During that same period, 16,020 mg were used from the fuel. Hence, approximately 2.4% of the fuel additive was deposited in the lube oil. This is a small proportion of the total, but the accumulative concentrations in the lube oil may be significant. If over a 200 hour period between oil changes, manganese is deposited at approximately 50 mg/hr. the lube oil concentration would be 500 mg Mn/litre oil. Concentrations of this order may be of some concern in the disposal of the lube oil, since the OSHA TLV is 5 mg/cm^3 or 5000 mg/L (see Lubrizol Material Safety Data Sheet in Appendix I). In retrospect, it may have been of interest to check the oil filter for manganese deposits.

All sampling for the determination of manganese in the engine exhaust was performed while the engine was operating over the MTU MOD 4 LHD Cycle. This is a simulated work cycle of an underground mining LHD (Load Haul Dump) vehicle. This cycle is 2-1/2 minutes in length with average conditions of 2160 rpm and 405 N.m. Figures 4 and 5 show a typical MTU MOD 4 Cycle on a second-by-second basis.

Initial samples were taken with the engine running on neat diesel fuel, and no fuel additives, to check for possible background manganese. As shown in Table 4, manganese concentrations were below detection limits. With the engine running on fuel containing 71.3 mg Mn/L, a raw exhaust concentration of 1870 Aug

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Mn/m^3 was determined. With the DPFs installed and 67.5 mg/L fuel manganese, an exhaust gas concentration of 47.5 µg Mn/m^3 was found. The DPF efficiency in filtering out the manganese is summarized in Table 3 below.

TABLE 3 - DPF MANGANESE FILTRATION EFFICIENCY

<u>Baseline Fuel Additive</u>	
Theoretical from Fuel	3610 $\mu g/m^3$
Measured in Exhaust	1870 $\mu g/m^3$
Loss in Engine	48%
<u>DPFs Installed</u>	
Theoretical from Fuel	3440 $\mu g/m^3$
Measured Downstream of DPFS	< 94 $\mu g/m^3$
Engine/DPF System Efficiency	98.6%
DPF Efficiency	> 97.3%

As can be seen, DPFs are very good, removing > 97.3% of the exhaust gas manganese. However, 48% of the fuel additive was lost in the engine system. As discussed earlier, only 2.4% was found in the lubrication oil. Therefore, it appears that a very significant portion of the fuel manganese was being deposited in the engine. This leads to the question of the effect of these deposits on long term engine operation. However, as far as the impact on environmental manganese emissions is concerned, the ceramic DPF proved to be very efficient in removing manganese from the engine exhaust.

Total particulate emissions were also measured during the additive tests. The results are shown in Table 5. The manganese fuel additive was found to reduce total particulate emissions by 11%. Similar effects by fuel additives have been found in previous work. Filtration efficiency for the fuel additive/DPF systems was found to be 96%.

6. TASK 3 - DEGUSSA CATALYZED DPF EVALUATION

Catalyzed DPFs are the simplest regenerative emissions control system because there is no need for additional hardware. Precious metal catalysts can convert SO_2 to H_2SO_4, which may be of concern in underground mining applications. In this program,

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two ceramic DPFs (designated as Type I and Units 36C and 37C) were coated with a base metal catalytic formula reported to have no SO_2 to H_2SO_4 conversion. These types of formulations, however, are not as good in reducing trapped particulate ignition temperatures. Therefore, a second set of DPFs were coated with a combined base/precious metal formula. These traps were designated Type II and Units 38C and 39C. The catalyzing of the DPFs was performed by Degussa in Germany.

6.1 MTU Cycles - Modifications and Analysis

For the Degussa evaluations, the LHD cycle developed from underground data taken at Michigan Technological University (MTU), or a modification of this cycle, was to be used. In preparing for the evaluation, it was deemed an appropriate time to make modifications of the MTU and MTU MOD 5 cycles. The MTU cycle is considered a relatively cool LHD cycle, while the MTU MOD 5 cycle is representative of a hotter LHD cycle. Both cycles were in a form that would not be easily transferable to another research test facility. Since ORF's role in the underground pollution control systems development is winding down, the cycles needed to be in a more easily transferable form.

The main problem was that portions of the cycles were requesting loads greater than 100% loads, in order to drive the load up more quickly. Therefore, the following steps were taken to make both cycles more easily reproductible by other facilities.

1. The actual engine speed and torque as output from the engine, was used as the new cycle input, or requested engine speed and torques. (Thus the cycles would remain essentially the same).

2. Of these inputs, those loads that were greater than 97% of the torque curve (for the Deutz F8L-413 FW) were reduced to the 97% level.

3. In order to return the cycle average torque to where it had been, torque was added uniformly across the cycle.

4. The process control coefficients were optimized to bring the new outputted cycles as close as possible to the requested (demand) cycles. This included some adjustments to requested rpms in trouble areas of particularly rapid torque application.

This process yielded versions of the MTU and MTU MOD 5 cycles whose actual resultant speed and torque were essentially the same as the requested cycle speed and torque. The resultant cycle averages and basic second-by-second makeup of both the cycles were basically unchanged from the previous cycles. So, essentially, just the requested cycles were altered.

Statistical analyses were then performed to determine how closely ORF's control system could reproduce a required cycle.

This transient cycle analysis was based on EPA's procedure for Heavy Duty Diesel Engines. Details of the analyses, graphic comparisons of requested and actual points and a detailed description of the procedure, are contained in Appendix II.

The statistical analyses are summarized in Tables 5 and 6. These results show that the MTU cycle meets all the EPA criteria. The MTU MOD 5 cycle meets all the criteria except for the y intercept and coefficient of determination in the speed analysis. This was because the MTU MOD 5 cycle is a heavily-loaded cycle, where, at times, the actual engine speed lags behind the requested speed.

6.2 Test Conditions

The identical test cell, equipment and engine were used as in Task 2 for the fuel additive testing. The test fuel was Gulf Diesel 40 with a fuel sulphur content of 0.13% by mass.

The durability and emissions testing was performed with the engine running on the MTU MOD 5 LHD cycle. Figures 5 and 6 illustrate typical torque and speed traces during the cycle. Typical average engine conditions for the cycle are 2125 rpm and 435 N.m.

6.3 Ignition Temperatures

For these tests, ignition temperature was defined as the exhaust gas temperature at which particulate material was depositing on the DPF, at the same rate particulate material was being burned-off.

The base metal DPFs (36C and 37C) were tested first by loading the DPF with particulate material. This was done while operating the engine at a steady-state condition of 2200 rpm and 180 N.m. (~30% load). Differential pressure drop was measured across the DPF to monitor the DPF loading and the DPF loaded until the differential pressure had increased by 2 kPa.

Test 1, as shown in Figure 8, began igniting at the first test condition. Normally, the test starts at an engine load at which the DPF is loading up. Torque is then increased in 20 N.m. steps until the DPF differential pressure starts to drop, indicating the ignition temperature has been reached.

The first test indicated an ignition temperature less than 400^{o}C. Figure 9 shows the results to be between 395^{o}C and 405^{o}C after re-loading the DPFs at 2200 rpm/180 N.m. A final test was run after the completion of the emissions and durability testing (approximately 25 hours of engine testing). This test indicated

an ignition temperature of 415°C-425°C. This higher ignition temperature may be due to catalyst ageing and/or ash build-up on the DPF surfaces.

Both ignition temperature tests for the base/precious metal DPFs were performed after the emission and durability tests (approximately 40 hours of engine testing). Figures 11 - 13 demonstrate an ignition temperature of 395°C - 405°C. Therefore, the aged ignition temperature of the base/precious DPFs was 395°C - 405°C compared to 415°C - 425°C for the base metal DPFs.

6.4 Durability

Of primary importance for any DPF system is its ability to self-regenerate without any additional assistance. The lower the required exhaust temperatures for particulate ignition, the better. Based on ignition temperature tests and previous experiences, the MTU MOD 5 cycle was chosen for durability testing because its average exhaust gas temperature is 420 °C. Figures 14 and 15 illustrate the DPF loading (using differential pressure) for the two types of catalyst formula. First, the base metal DPF is shown to have operated successfully for 24 hours. The base/precious metal DPF operated under regenerative conditions for almost 40 hours. Both types are compared in Figures 16 and 17 on the same time and pressure scales.

Both types had varied pressure traces during the durability testing, with times of rapid build-up, rapid decline and relative stability. These variations are due to a combination of the degree and nature of trap particulate loading (i.e. total amounts of soluble and/or insoluble material) and variability in exhaust gas temperatures. Variability in exhaust temperatures is shown in Table 7. As can be seen in the table, these variations (cycle averages varied from 398°C to 445°C) are due in large part, to changes in temperature of combustion air and cooling air. In comparing Table 7 temperatures with the durability test Figures 15 and 16, the variations in exhaust temperature from day-to-day, do appear to impact on DPF loading rates.

These two catalyzed DPF types were shown to be regenerative over the MTU MOD 5 cycle. However, the data does show regeneration is not dependent upon the cycle alone, but also on many other factors, including ambient air temperature, particulate loading, etc.

6.5 Gaseous Mass Emissions

Gaseous mass emissions for the baseline engine and with the two types of DPFs, are summarized in Table 8. For the base metal DPF, there were no significant reductions or increases, except possibly with the NO_2, which was reduced by 40%. This will be

addressed below. The base/precious metal DPFs reduced total hydrocarbons by 23%, carbon monoxide by 97% and nitric oxides by 10%. All emission comparisons were averaged from results over the MTU MOD 5 LHD cycle.

Variability of NO, NO_2 and NO_x results, as shown in Table 8, led to questions of whether the NO_2 and NO reductions were real. It was felt that probably these were just test-to-test variations. To check this, a series of steady-state tests were performed with the DPFs installed on the engine. Oxides of nitrogen concentrations were then measured using a heated line to take the samples before and after the DPFs. Load conditions of 95%, 75%, 50% and 25% were used in order to check for any temperature-related catalyst effects.

Results in Table 9 for nitric oxides and total oxides of nitrogen, show no significant trends. Nitrogen dioxides show some major changes but do not show any real trends. Considering the low NO_2 concentrations relative to the 0-1000 ppm range being used, these changes observed are probably not significant. Therefore, in conclusion, there are no significant effects on the oxides of nitrogen emissions by either of the catalyst formulas.

6.6 Particulate and Sulphur Emissions

As expected (see Table 10) particulate filtration was excellent and similar for both types of catalyzed DPFs. The base metal DPF reduced solubles by 95% and insolubles by 98%, while the base/precious DPF reduced solubles by 94% and insolubles by 98%. These values were obtained during the MTU MOD 5 cycle, with the DPFs in a regenerative mode.

One of the main points of interest with these two catalyst formulas, was the effect on sulphur emissions. These tests were also performed during the cycle and during regenerative conditions. The results (see Table 11) were very promising considering the high average temperature of the cycle. Baseline results (i.e. stock engine with no pollution control devices) showed 6.1% H_2SO_4. The base metal DPF yielded only 1.8% H_2SO_4. This value, lower than the baseline, may indicate some H_2SO_4 storage was taking place, although because the traps were in a relatively regenerative mode, this would not be expected. The base/precious metal DPF yielded 10.5% H_2SO_4 which is a significant improvement over precious metal catalyst formulas.

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6.7 Ames Mutagenicity Assay

Particulate samples were analyzed on tester strain TA-98 without metabolic activation. Results were as follows:

Sample	Total Particulates mg/m^3	Soluble Particulates mg/m^3	Mutagen Concen., Rev./m^3	Specific Activity Rev./µg
Baseline	58.0	14.54	36,350	2.5
Base Metal	2.8	1.04	2,402	2.4
Base/Precious Metal	*20.8	0.79	1,580	2.0

* spurious result.

As can be seen, revertants per cubic metre of exhaust is greatly reduced for both DPFs, 93% reduction for the base metal and 96% for the base/precious metal. Also, the revertants per ug of soluble particulates was slightly reduced. This is also a significant result, as precious metal catalysts have been known to increase the specific activity.

6.8 Polynuclear Aromatic Hydrocarbons

Particulate samples were also collected for the PAH analysis. A blank sample (i.e. ambient test area air), baseline engine sample and a base/precious DPF sample. Only the base/precious DPF was tested, as this result was deemed the most significant.

Table 12 summarizes the concentrations and mass emissions of PAHs found. As shown, there were no detrimental effects by the catalyzed DPF, but in fact, reduced all PAH by >93% except for fluoranthene, which was reduced by 21%. This is what would be expected, as in the Table, the PAHs are listed with the most volatile first (fluoranthene) down to the least volatile (benz[ghi]perylene). Therefore, basically, the percent reduction increases as the volatility decreases.

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TABLE 2 - OIL AND FUEL MANGANESE CONCENTRATIONS

Oil Analysis

Test Condition	Cumulative Engine Hours	Manganese mg/L	Volume litres	Total Oil Manganese (mg)	Gain mg.
Initial Start-Up	0	8	20	160	0
After Baseline	3.2	11	19	209	49
After Fuel Additive	5.6	18	18	324	164
After DPF/ Fuel Additive	10.2	30	20	595	435

Fuel Analysis

Test	Engine Hours	Fuel Mn mg/L	Fuel Consp. g/s	Total Mn Used mg	Engine Exhaust m^3/min.	Theoretical Raw Exhaust Manganese $\mu g/m^3$
Baseline	3.2	<0.3	7.82	<16	11.10	< 8
Fuel Add.	2.4	71.3	7.89	5,720	10.99	3610
DPF + Fuel Add.	4.6	67.5	7.83	10,300	10.68	3440

TABLE 4 - EXHAUST GAS MANGANESE CONCENTRATIONS

Test Condition	Total Filter Manganese (µg)	Impinger Solutions Concentration (µg/mL)	Impinger Solutions Volume mL	Impinger Solutions Total µg	Total Manganese (µg)
Baseline	<2	<0.02	650	<13	<15
"	<2	<0.02	748	<15	<17
"	<2	<0.02	659	<13	<15
Fuel Additive	293	0.04	719	29	322
"	312	0.04	672	27	339
"	267	0.04	666	27	294
DPF + Fuel Additive	14.2	<0.02	648	<13	<27
"	17.5	<0.02	669	<13	<31
"	12.5	<0.02	734	<15	<28

Test Condition	Total Manganese µg	Sample Volume m^3	Dilution Tunnel Ratio	Engine Exhaust Mn Con. $\mu g/m^3$	Average $\mu g/m^3$
Baseline	<15	0.798	4.77	< 90	
"	<17	0.765	4.77	<106	< 96
"	<15	0.782	4.77	< 92	
Fuel Additive	322	0.810	4.67	1856	
"	339	0.765	4.67	2069	1870
"	294	0.815	4.67	1684	
DPF + Fuel Add.	<27	1.492	5.02	< 91	
"	<31	1.690	5.02	< 93	< 94
"	<28	1.465	5.02	< 96	

TABLE 5 - TOTAL PARTICULATE MASS EMISSIONS - MTU MOD 4 CYCLE

Condition	mg/m^3	g/hr	g/kW.hr	g/Kg Fuel	% Reduction
Baseline	109	72.7	0.787	2.58	
"	110	73.1	0.791	2.60	
"	102	67.9	0.735	2.41	
Average	107	71.2	0.771	2.53	
Fuel Additive	98.5	65.0	0.720	2.29	
"	119	78.5	0.870	2.76	11%
"	66.7	44.0	0.490	1.55	
Average	94.7	62.5	0.690	2.20	
Fuel Additive + DPF	5.5	3.5	0.038	0.125	
"	4.0	2.5	0.028	0.090	96%
"	4.3	2.7	0.030	0.097	
Average	4.6	2.9	0.032	0.104	

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TABLE 7 - DURABILITY TESTS - AVERAGE ENGINE CONDITIONS

DEGUSSA Base Metal - Durability MOD 5 Cycle
Daily Averages

Date	ENGSP	CTORQ (N.m.)	L.Exhaust Temp. (°C)	R.Exhaust Temp. (°C)	Combustion Air (°C)	Cooling Air (°C)	Test Hours
Jan.31	2129	431.3	412.5	417.1	20.8	19.5	6
May 7	2062	444.6	437.7	445.1	27.5	28.6	19
May 8	2093	439.4	429.4	435.9	21.4	24.6	22

DEGUSSA Base/Precious Metal - Durability MOD 5 Cycle
Daily Averages

Date	ENGSP	CTORQ (N.m.)	L.Exhaust Temp. (°C)	R.Exhaust Temp. (°C)	Combustion Air (°C)	Cooling Air (°C)	Test Hours
Feb.22	2131	431.1	398.0	414.9	19.3	21.4	1
Feb.24	2132	429.8	407.6	412.0	14.4	22.0	3
Feb.25	2126	436.9	417.3	420.0	21.1	20.3	8
Feb.26							
(am)	2125	435.9	426.6	428.7	25.3	20.8	11
(pm)	2129	432.9	418.5	420.7	18.1	21.2	14
May 1	2100	445.5	431.9	442.3	24.2	23.3	28
May 2	2113	439.0	422.1	428.5	16.9	21.2	35

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TABLE 8 GASEOUS MASS EMISSIONS - DEGUSSA CATALYZED DPFS
- MIU MOD 5 CYCLE

		Baseline	Base Metal	% Change	Base/Precious Metal	% Change
CO_2	%	7.5	7.3		7.4	
	g/hr	87,900	87,600		87,400	
	g/kW.hr	900	901		902	
	g/Kg. Fuel	3,180	3,180		3,180	
THC	ppm	126	120		95.7	
	g/hr	53.8	52.3	- 3%	41.5	-23%
	g/kW.hr	0.550	0.543		0.429	
	g/Kg. Fuel	1.94	1.90		1.51	
CO	ppm	209	225		7.2	
	g/hr	156	172	+10%	5.4	-97%
	g/kW.hr	1.60	1.78		0.056	
	g/Kg. Fuel	5.66	6.24		0.20	
NO	ppm	629	662		565	
	g/hr	502	543	+ 8%	453	-10%
	g/kW.hr	5.13	5.65		4.66	
	g/Kg. Fuel	18.2	19.8		16.5	
NO_2	ppm	40	24	-40%	39	- 2%
	g/hr	50	30		48	
	g/kW.hr	0.51	0.31		0.48	
	g/Kg. Fuel	1.8	1.1		1.8	
NO_x	ppm	670	685		604	
	g/hr	817	858	+ 5%	765	- 6%
	g/kW.hr	8.36	8.90		7.94	
	g/Kg. Fuel	29.6	31.2		27.9	

TABLE 9 - OXIDES OF NITROGEN STEADY-STATE COMPARISON

Test Condition	NO_x		% Change	NO		% Change	NO_2		% Change
Base/Precious Metal	Before	After		Before	After		Before	After	
2200 rpm/95% load	640	658	+ 3%	622	618	- 1%	18	40	+ 120%
2200 rpm/75% load	694	676	+ 3%	616	628	+ 2%	78	48	- 38%
2200 rom/50% load	527	524	+ 1%	484	482	0%	43	42	- 2%
2200 rpm/25% load	317	317	0%	293	299	+ 2%	24	18	- 25%
Base Metal									
2200 rpm/95% load	742	751	- 1%	663	672	+ 1%	79	79	0%
2200 rpm/75% load	742	742	0%	638	660	+ 3%	104	82	- 21%
2200 rpm/50% load	578	586	+ 1%	517	524	+ 1%	61	62	+ 2%
2200 rpm/25% load	386	401	+ 4%	341	361	+ 6%	45	40	- 11%

TABLE 10 - TOTAL PARTICULATE EMISSIONS - DEGUSSA DPFs
- MTU MOD 5 CYCLE

Test	Soluble Particulates				Insoluble Particulates				Total Particulates			
	mg/m^3	g/h	g/kW.h	g/Kg. Fuel	mg/m^3	g/h	g/kW.h	g/Kg.Fuel	mg/m^3	g/h	g/kW.h	g/Kg. Fuel
Baseline	17.8	11.3	0.116	0.411	57.3	36.5	0.374	1.32	75.0	47.9	0.490	1.73
Degussa Base Metal DPFs (36C, 37C)	0.97	0.64	0.0066	0.023	1.00	0.66	0.0069	0.024	1.97	1.30	0.014	0.047
% Reduction			95%				98%				97%	
Degussa Base/ Precious DPFs (38C, 39C)	1.12	0.73	0.0073	0.026	0.79	0.52	0.0050	0.019	1.58	1.05	0.011	0.038
% Reduction			94%				98%				98%	

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TABLE 11 - SULPHUR EMISSIONS - MTU MOD 5 CYCLE
- DEGUSSA DPFs

Test	Concentrations				Mass Emissions					
	SO_2	$SO_4^=$	Total S	Theoretical S*	SO_2			$SO_4^=$		
	ppm	ppm	ppm	ppm	g/h	g/kW.h	g/Kg.Fuel	g/h	g/kW.h	g/Kg.Fuel
Baseline	44.4	2.7	47.1	41.6	77.1	0.78	2.80	7.1	0.075	0.26
% SO_4			6.1% SO_4							
Base Metal DPFs	42.7	0.8	43.5	41.6	74.7	0.77	2.71	2.2	0.022	0.078
% SO_4			1.8% $SO_4^=$							
Base/ Precious Metal DPFs	37.4	4.4	41.9	41.6	64.2	0.66	2.34	11.5	0.12	0.42
% SO_4			10.5% $SO_4^=$							

* as calculated from a fuel sulphur of 0.13%.

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TABLE 12 - POLYNUCLEAR AROMATIC HYDROCARBONS
(Concentration ng/sample)

PAH	Blank Filter	Blank PUF	Baseline Filter	Baseline PUF	Base/Precious DPF Filter	Base/Precious DPF PUF
F	604.44	47.85	37.25	298.35	249.33	1522.80
B[a]A	247.41	76.84	23.24	97.76	16.49	133.52
B[k]F	130.46	15.42	11.18	24.62	5.63	8.16
B[a]P	449.22	12.91	18.58	22.45	<5.00	11.42
Dibenz [ah]A	349.61	<7.00	15.14	<7.00	7.02	<7.00
Benz [ghi] Per	780.68	<15.00	35.08	<15.00	15.16	<15.00

PAH Emissions - MTU MOD 5 Cycle
(corrected for Blank)

PAH	Baseline		Base/Precious DPF		% Reduction
	µg/m^3	µg/h	µg/m^3	mg/h	
F	0.404	0.271	0.328	0.213	21%
B[a]A	0.138	0.093	0.009	0.006	93%
B[k]F	0.037	0.024	0	0	100%
B[a]P	0.017	0.011	0	0	100%
Dibenz [ah]A	0	0	0	0	-
Benz [ghi] Per	0	0	0	0	-

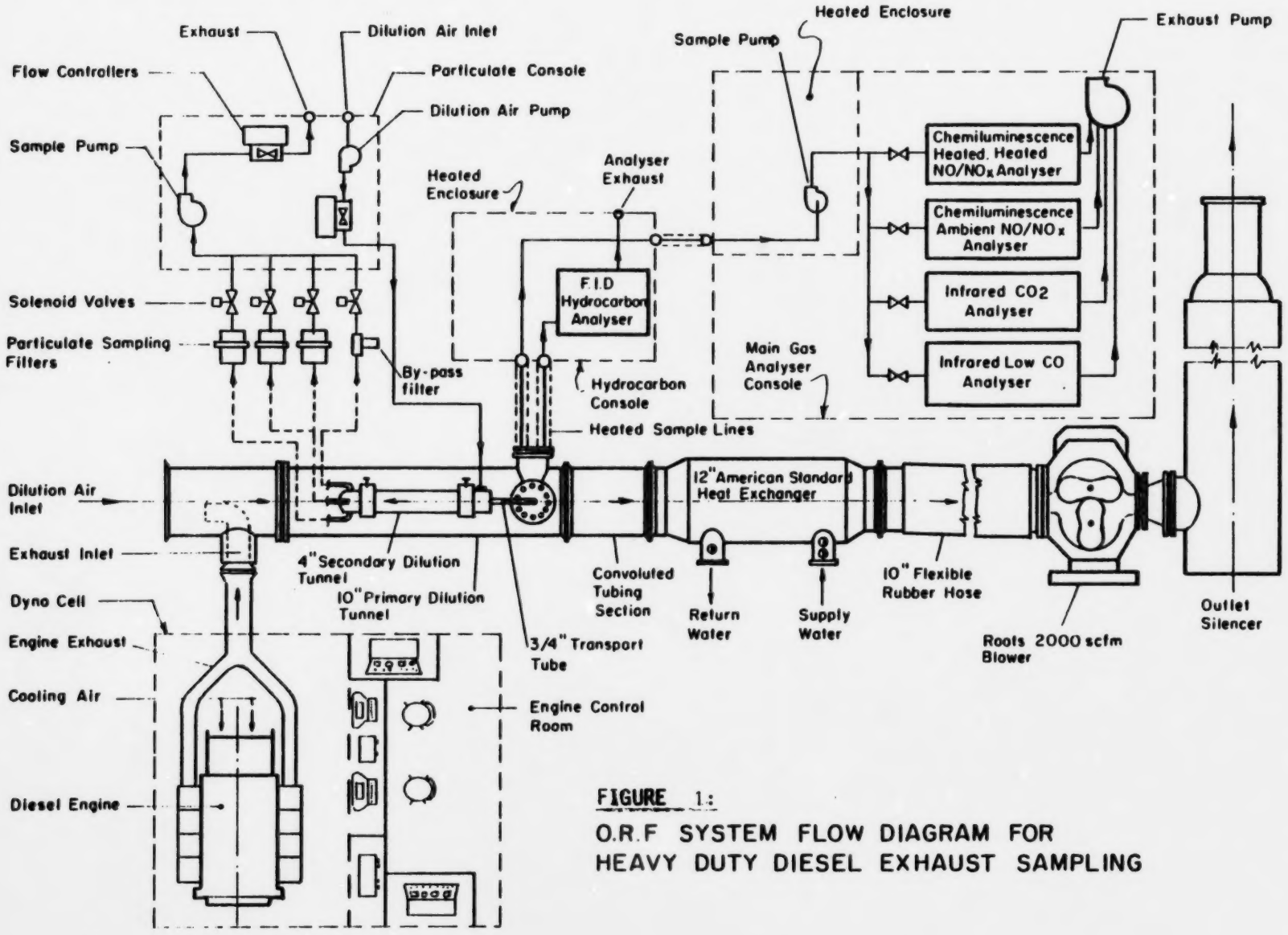


FIGURE 1:

O.R.F SYSTEM FLOW DIAGRAM FOR HEAVY DUTY DIESEL EXHAUST SAMPLING

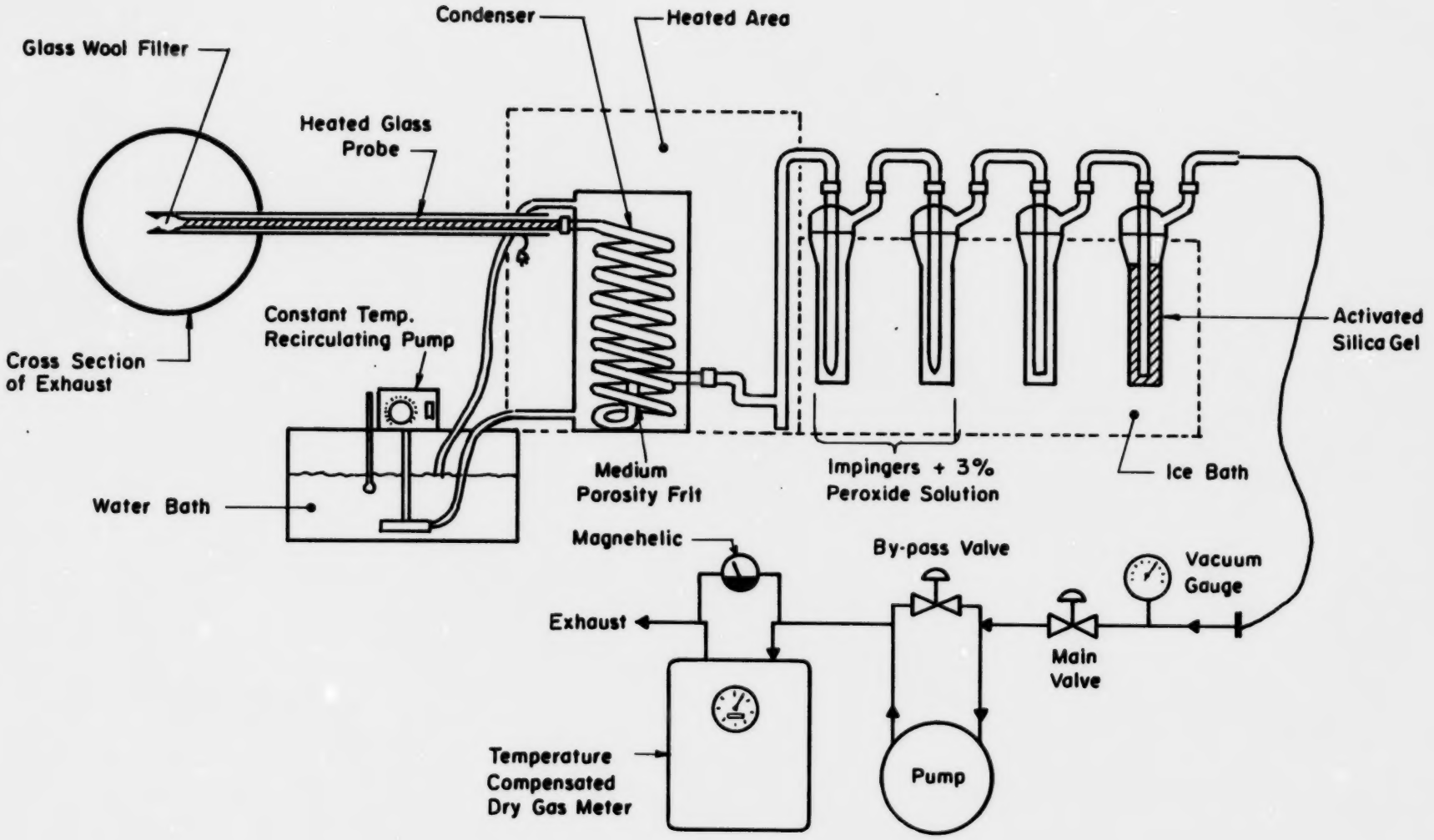


FIGURE 2: SULPHATE SAMPLING TRAIN SCHEMATIC

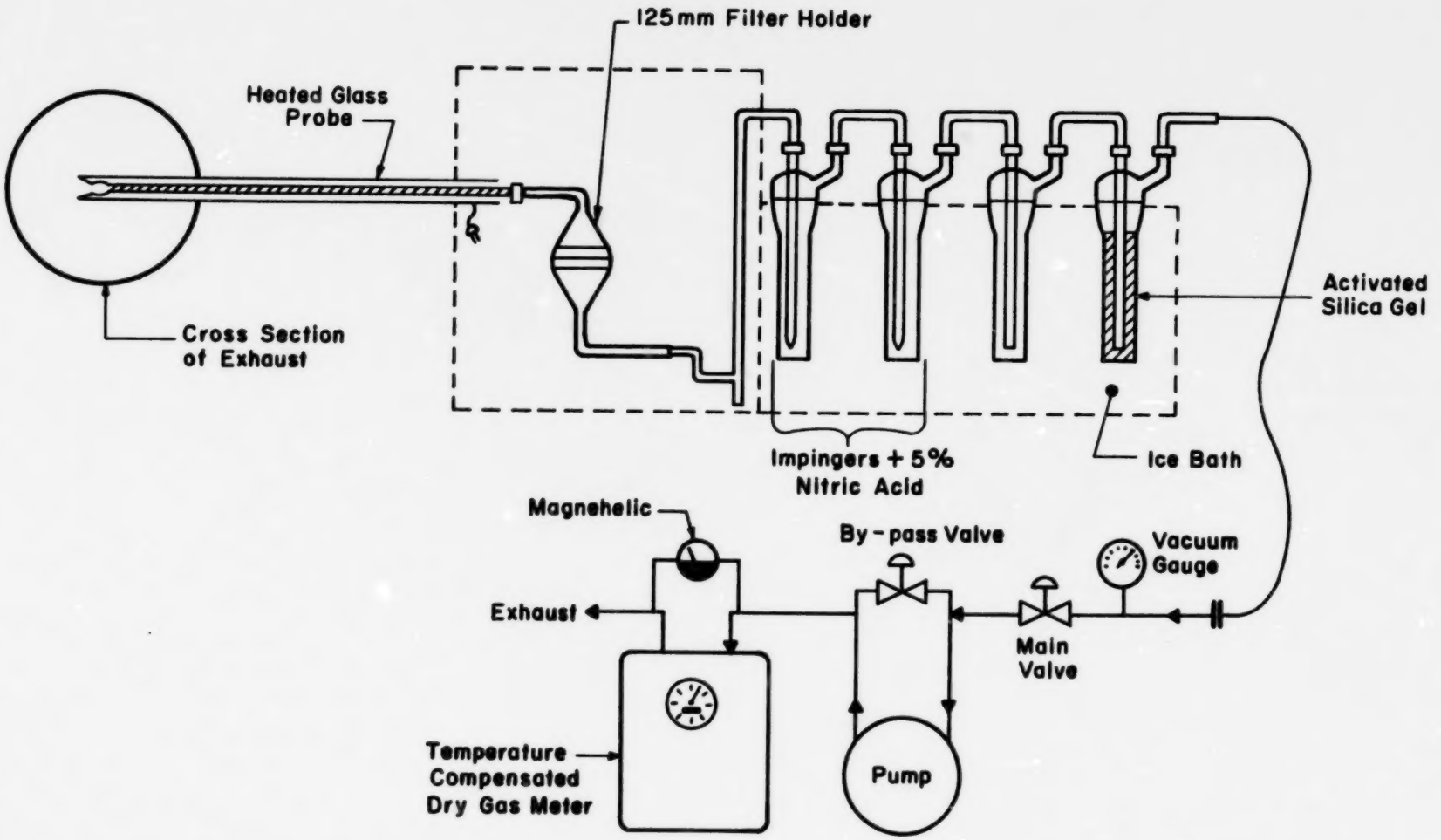


FIGURE 3: . MODIFIED EPA METHOD #5 SAMPLE TRAIN.

FIGURE 4:

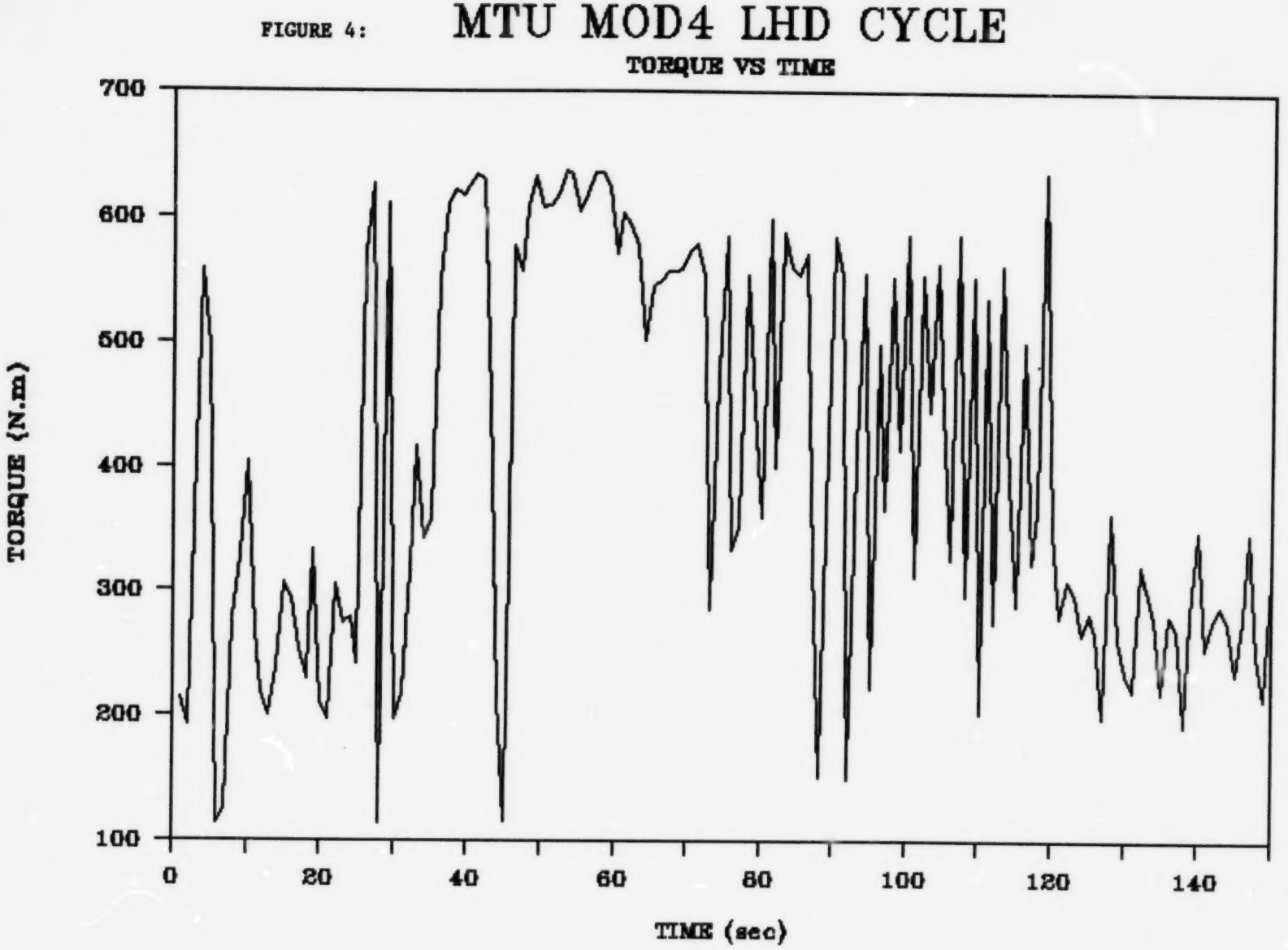

MTU MOD4 LHD CYCLE
TORQUE VS TIME
TORQUE (N.m)
700
600
500
400
300
200
100
0
20
40
60
80
100
120
140
TIME (sec)

FIGURE 5: MTU MOD4 LHD CYCLE

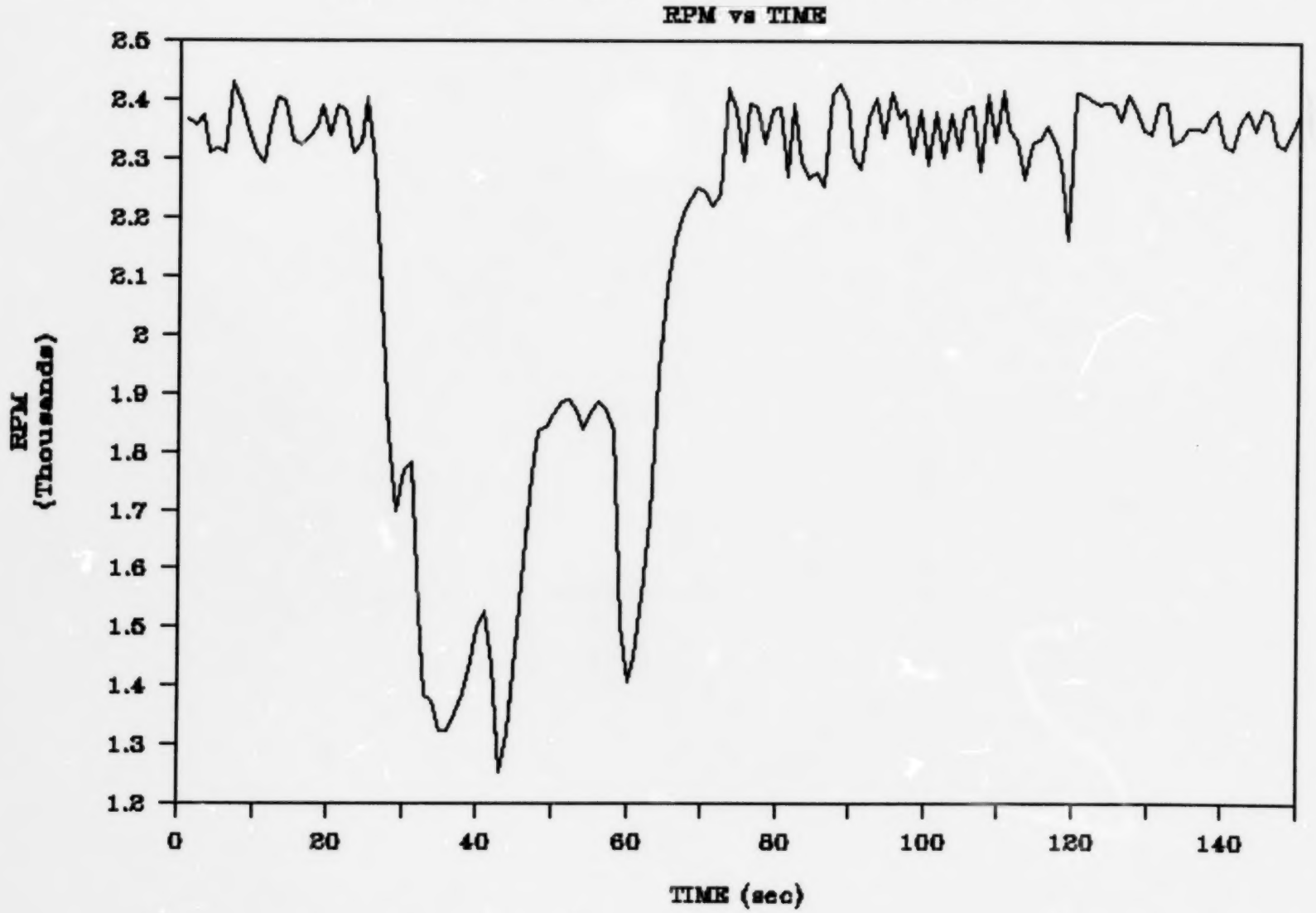


FIGURE 6: MTU MOD 5 LHD CYCLE

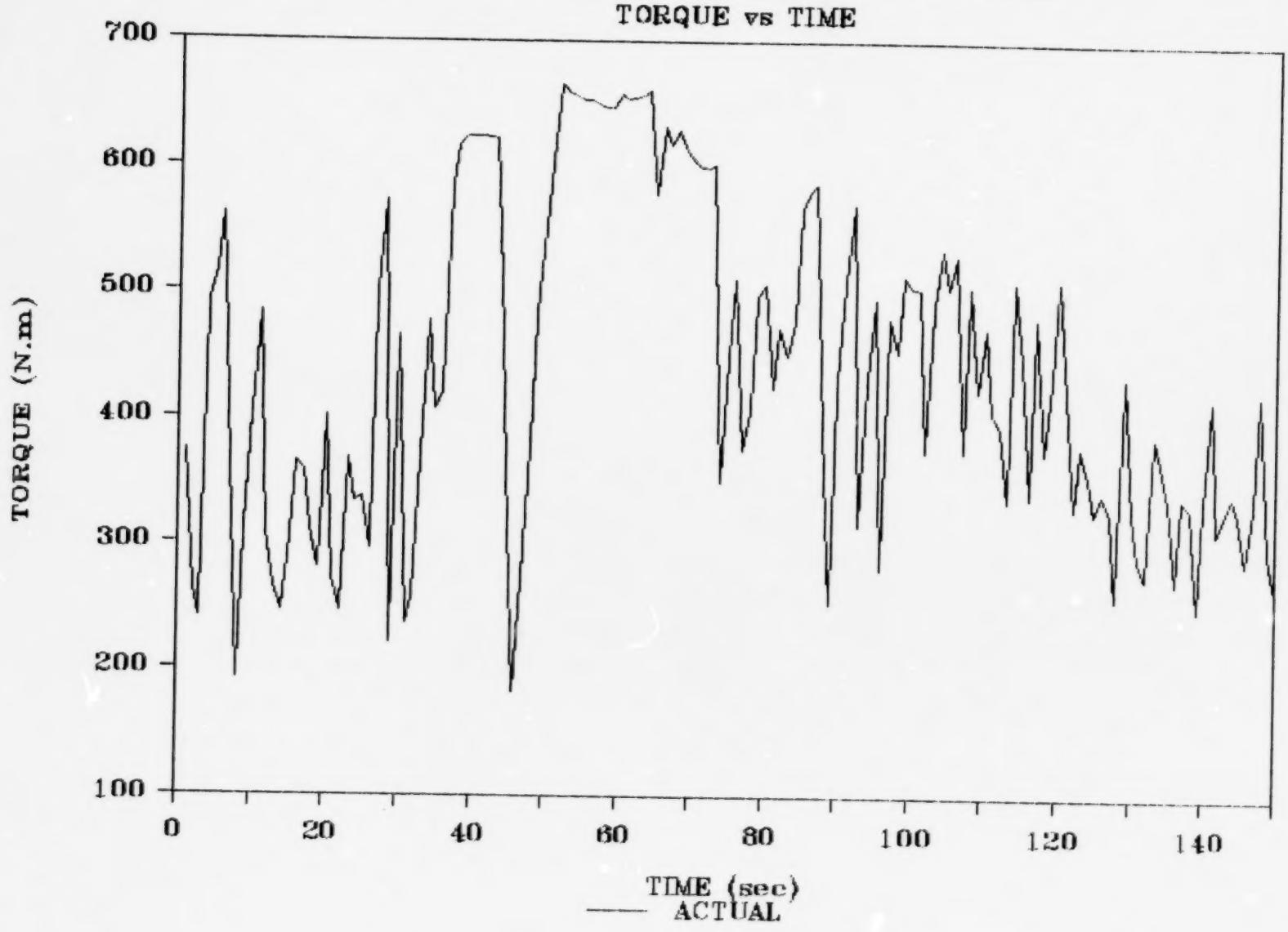


FIGURE 7:

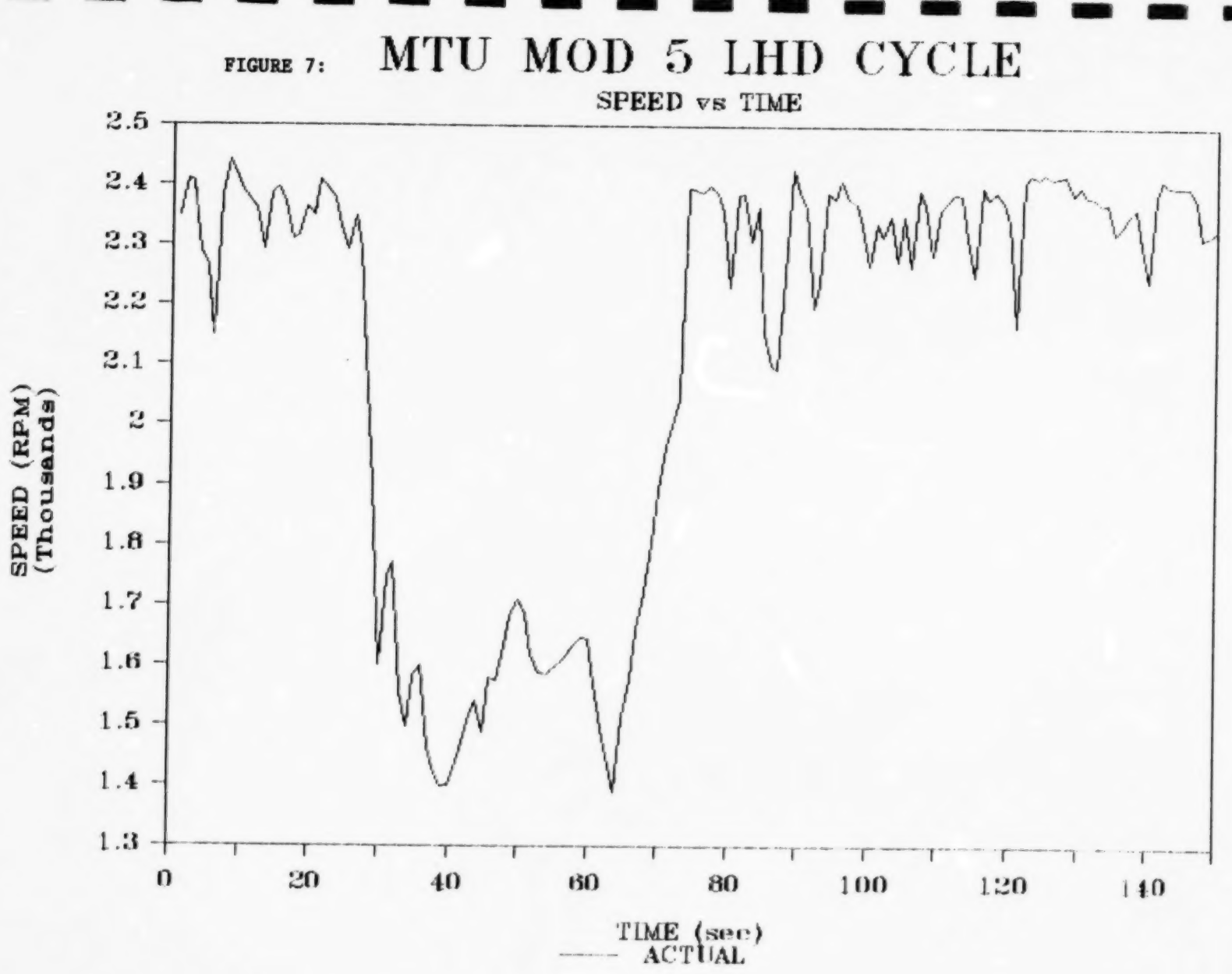

MTU MOD 5 LHD CYCLE
SPEED vs TIME
SPEED (RPM)
(Thousands)
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
0
20
40
60
80
100
120
140
TIME (sec)
ACTUAL

FIGURE 8

IGNITION TEMPERATURE 1 (celcius)

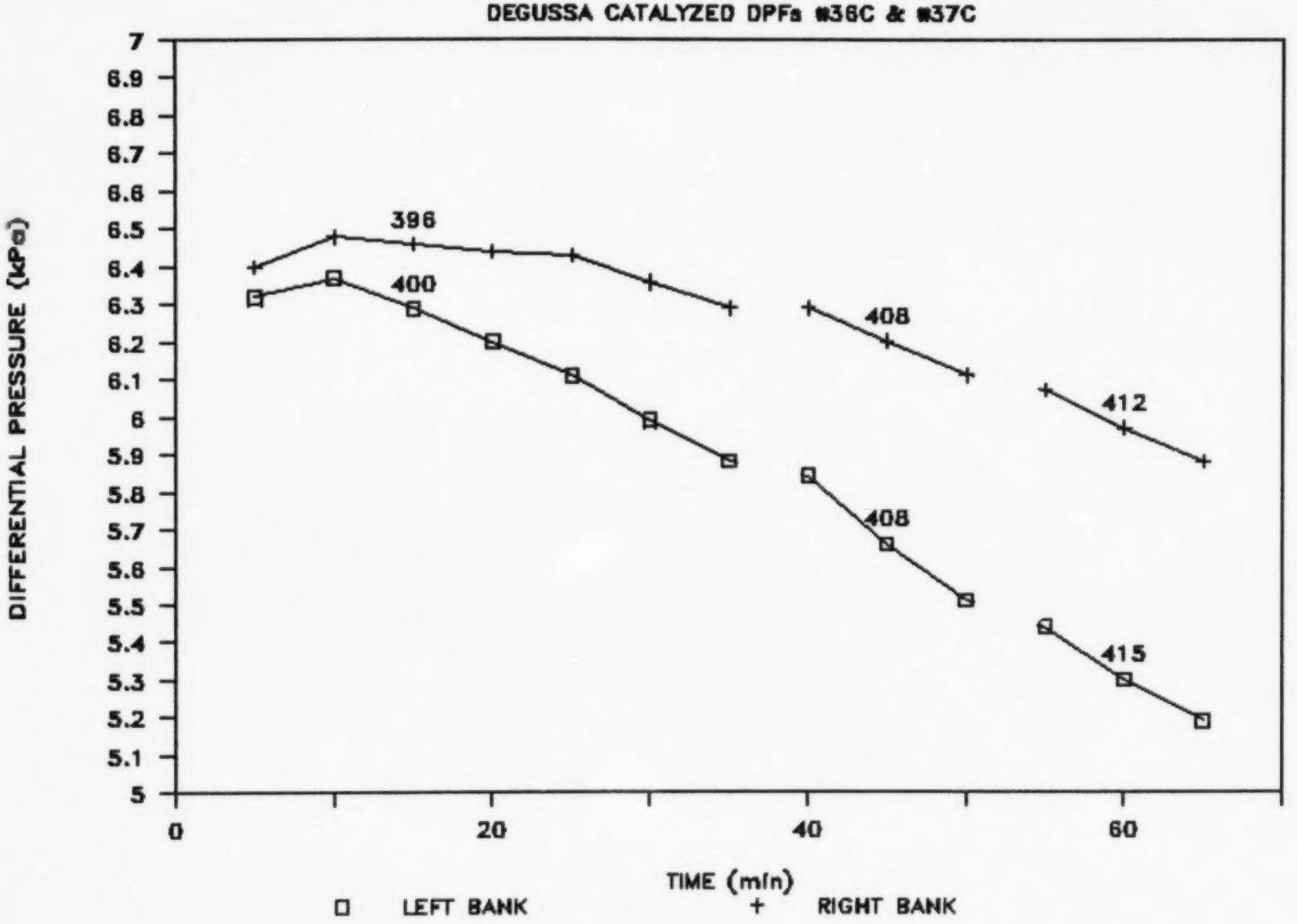


FIGURE 9

IGNITION TEMPERATURE 2 (celcius)

DEGUSSA CATALYZED DPFs #36C & #37C

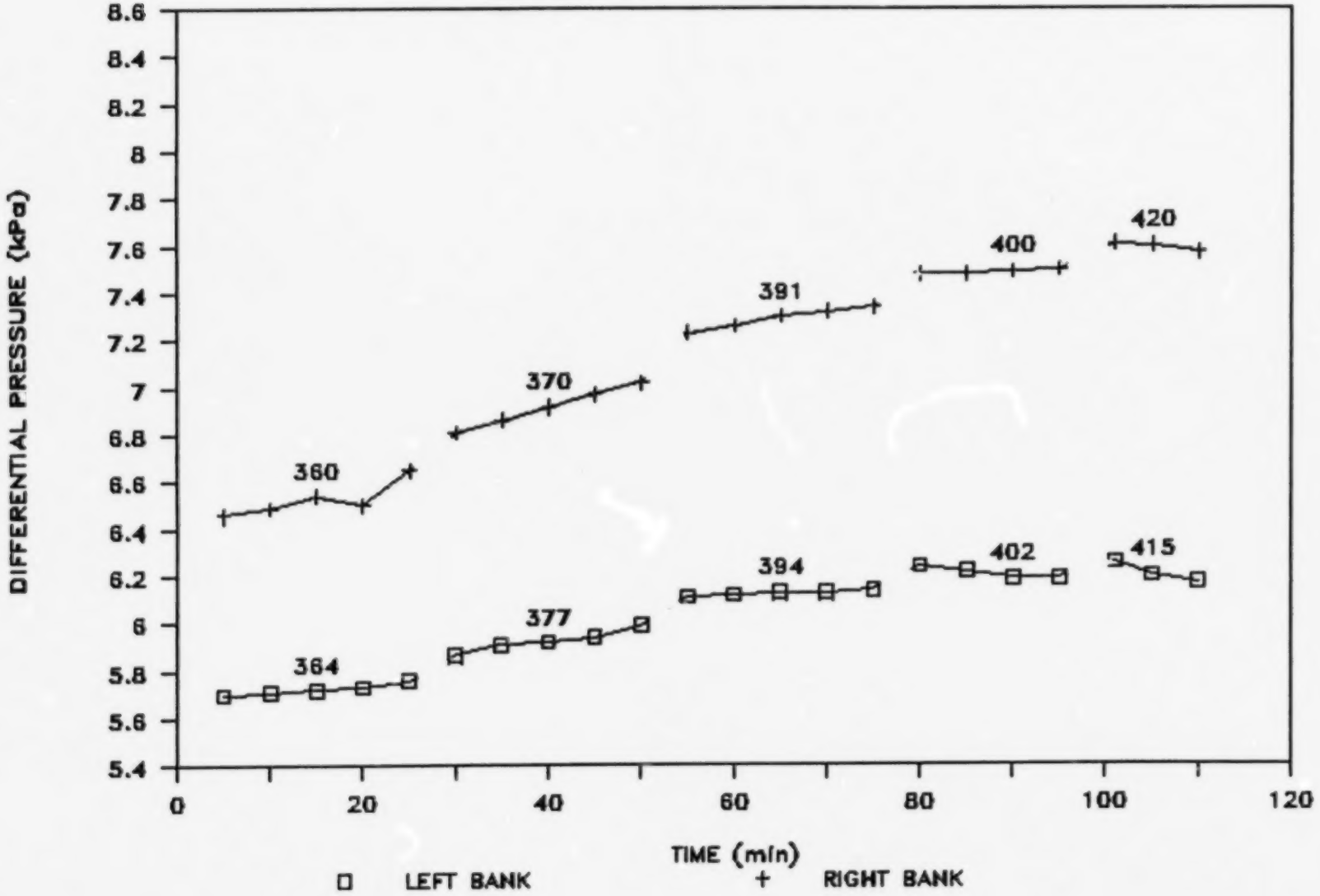


FIGURE 10

IGNITION TEMPERATURE #3 (DEGREES C)

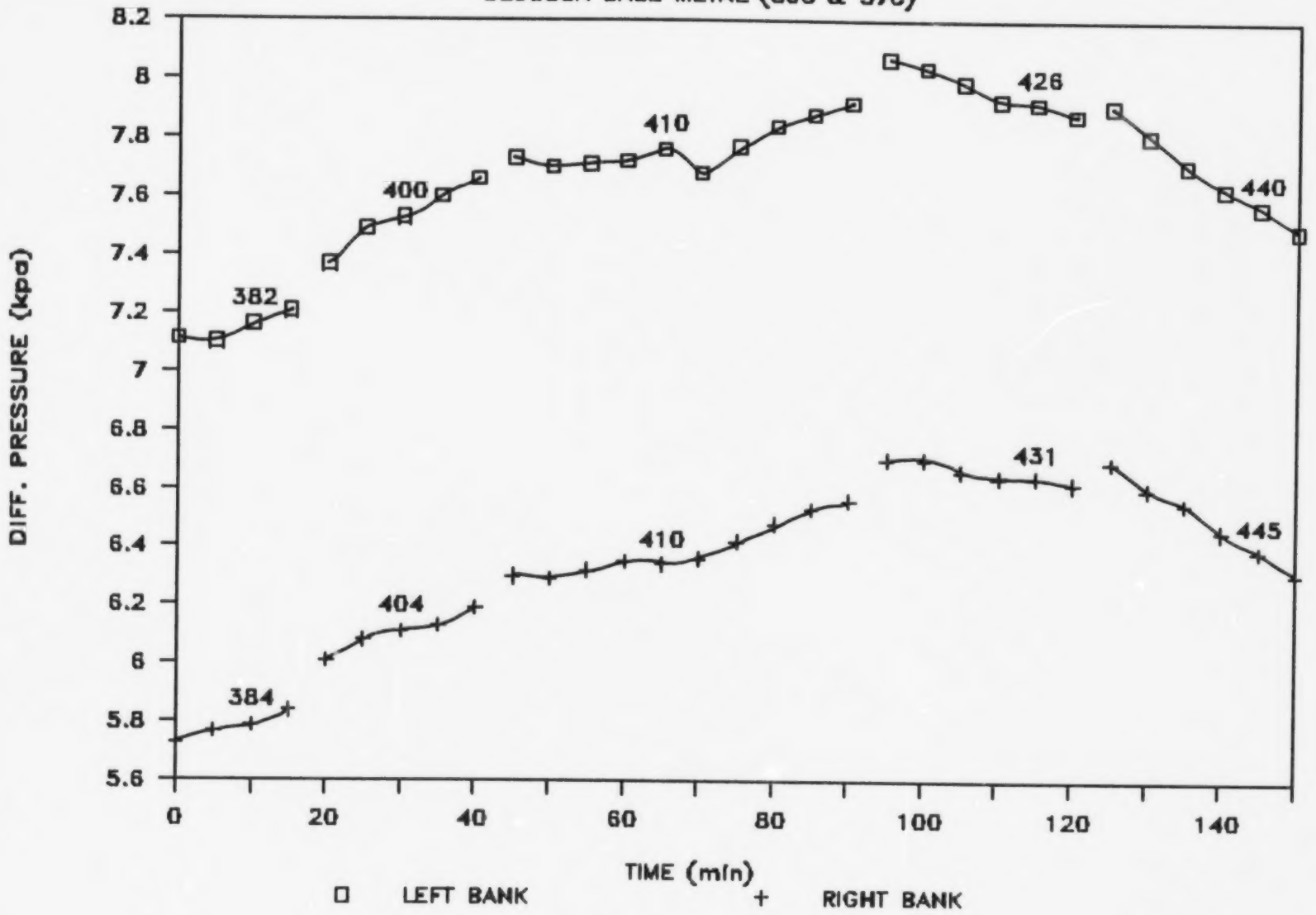
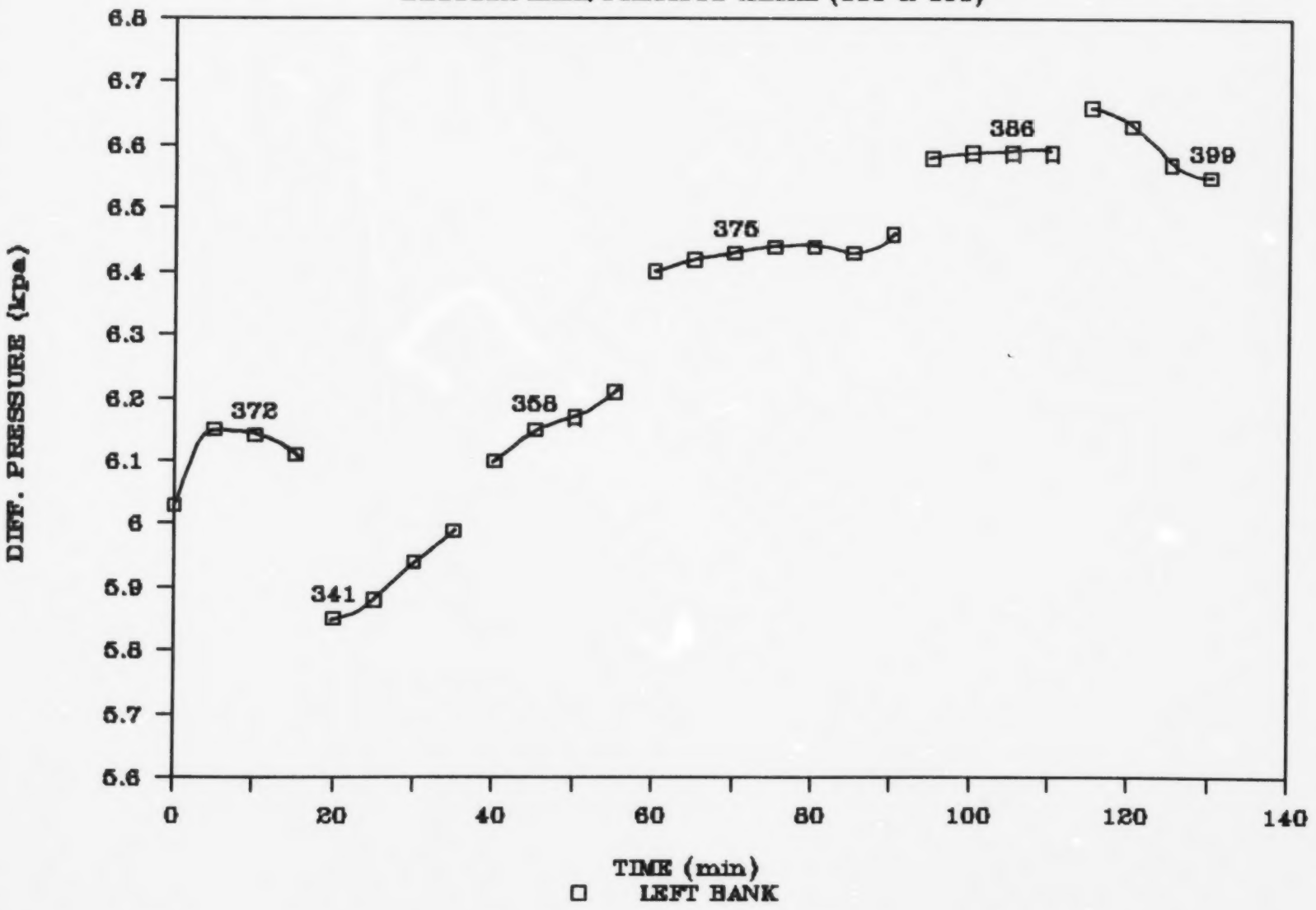


FIGURE 11

IGNITION TEMPERATURE #1 (DEGREES C)



IGNITION TEMPERATURE #1 (DEGREES C)

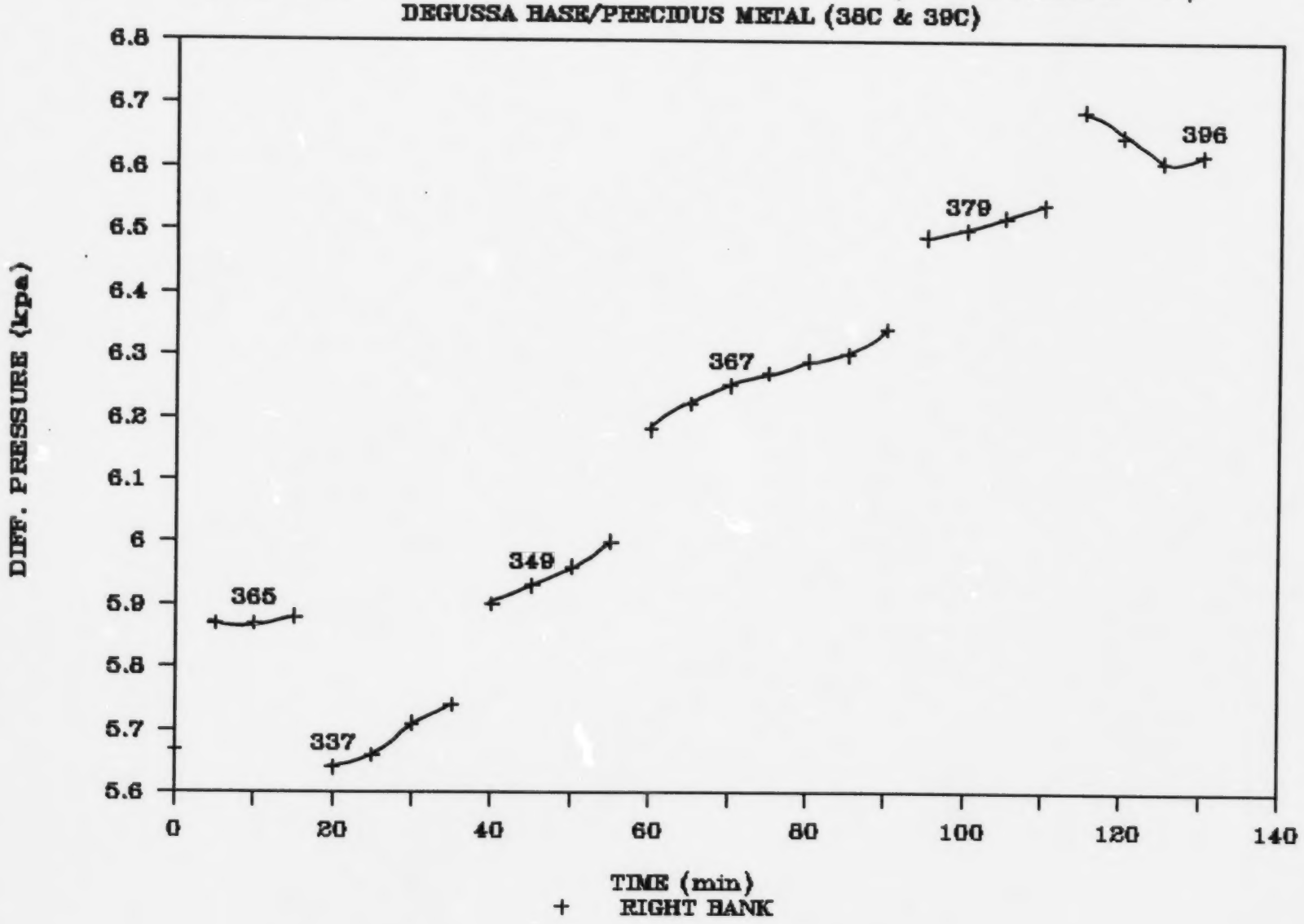


FIGURE 13

IGNITION TEMPERATURE #2 (DEGREES C)

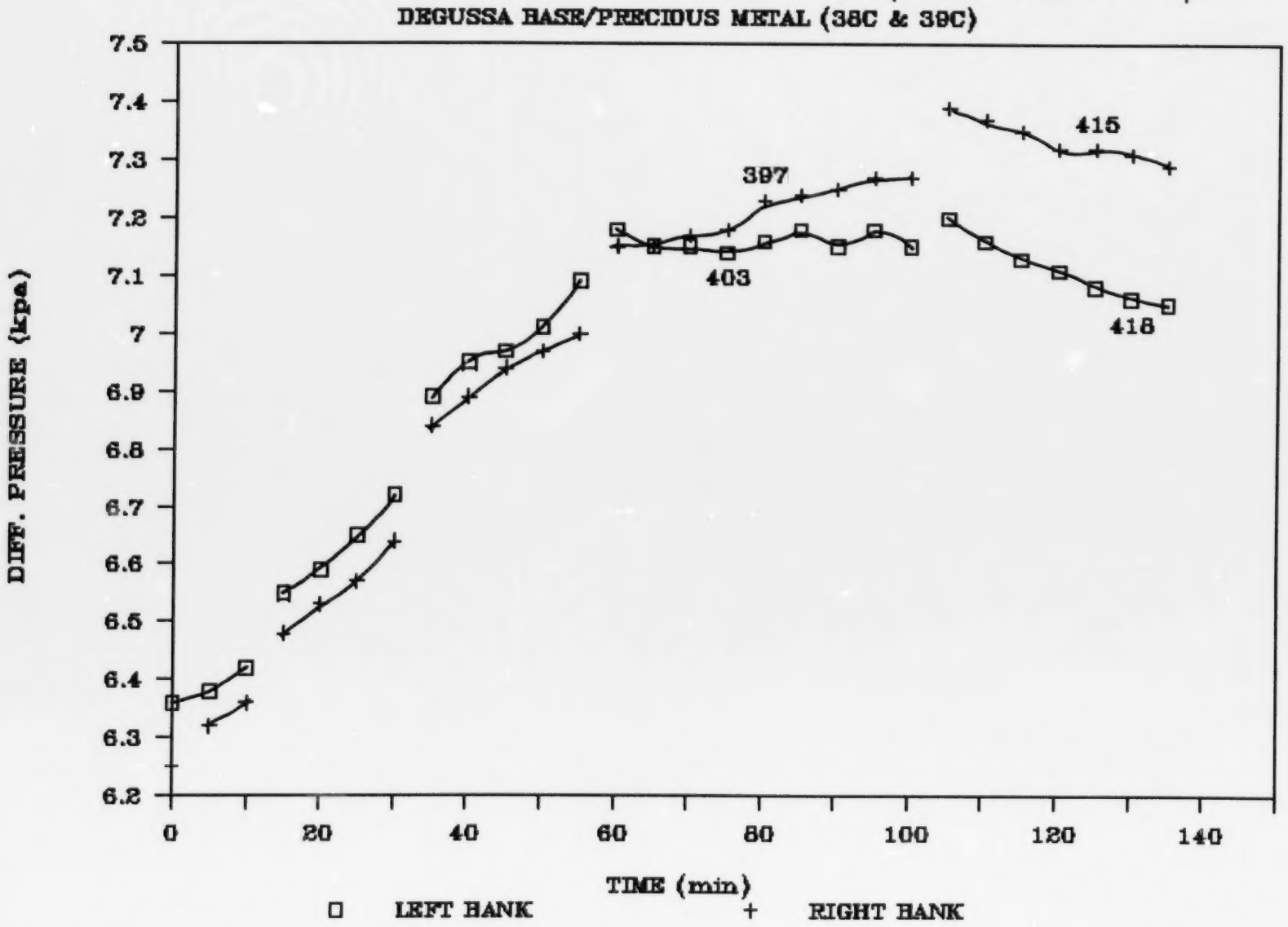


FIGURE 14: CATALYZED DPFS 36C & 37C

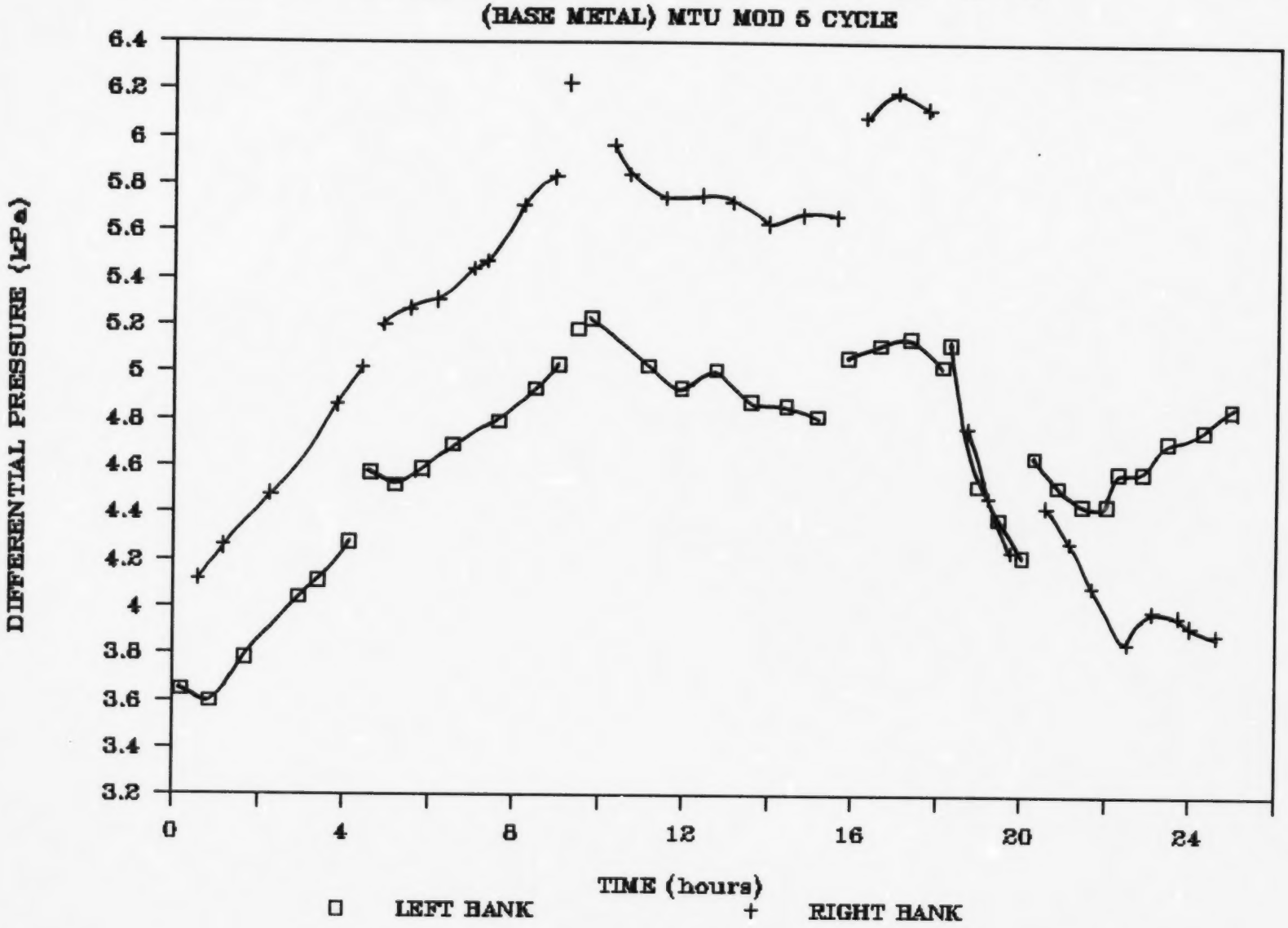


FIGURE 15: CATALYZED DPFS 38C & 39C

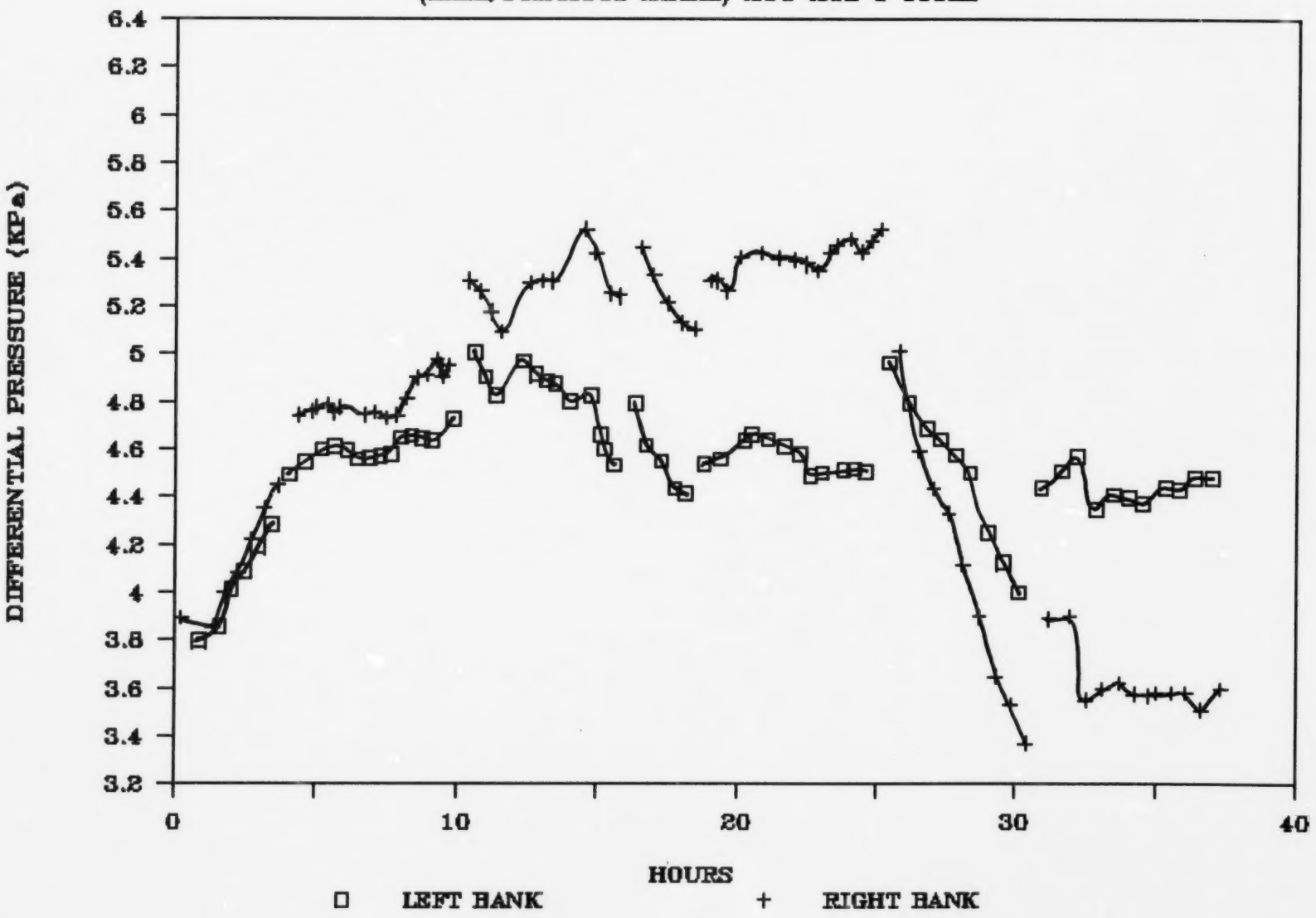


FIGURE 16: CATALYZED DPFS 36C & 37C

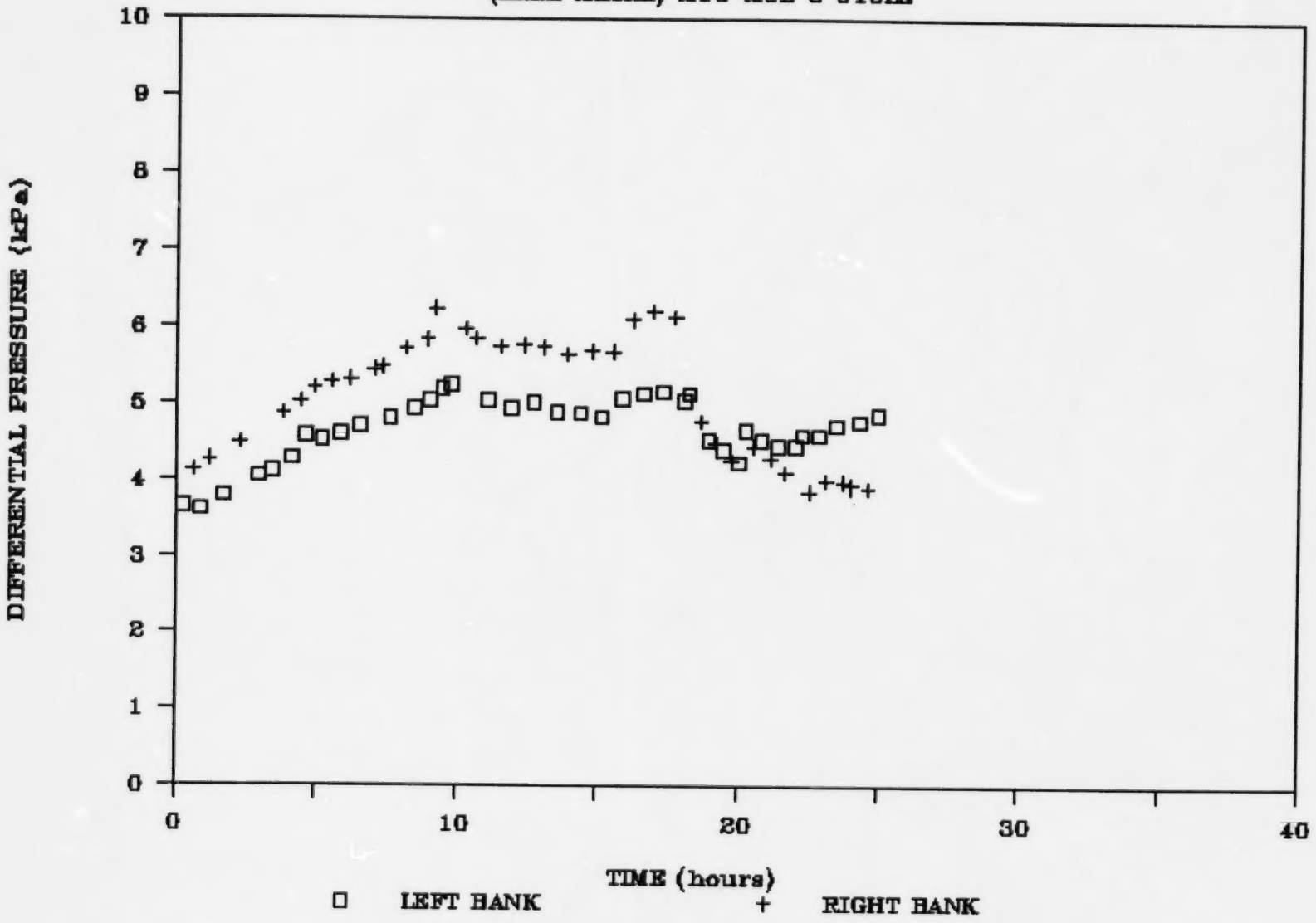
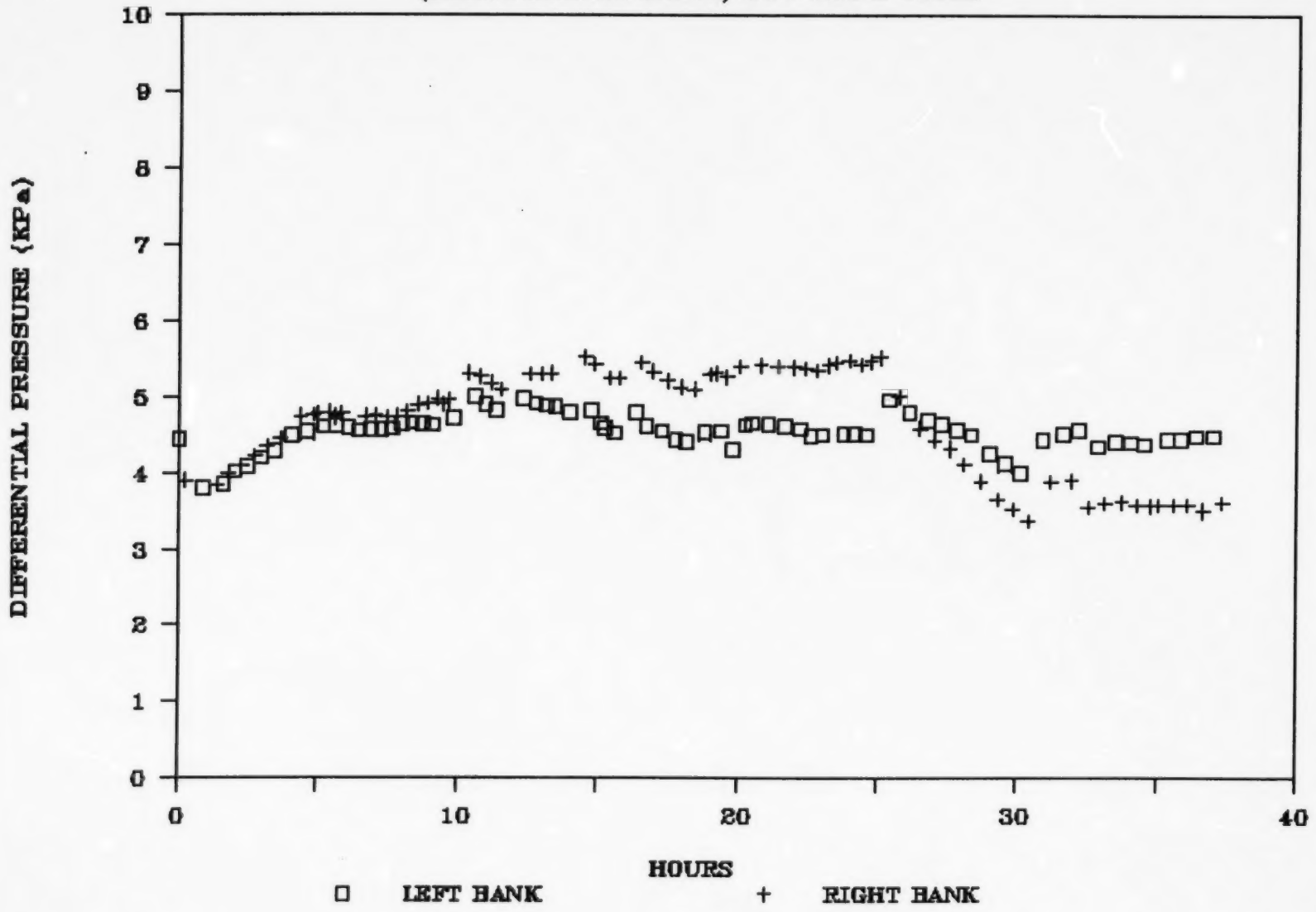


FIGURE 17: CATALYZED FILTERS 38C & 39C

(BASE/PRECIOUS METAL) MTU MOD 5 CYCLE



APPENDIX I

FUEL ADDITIVE SAFETY DATA SHEETS

"THE INFORMATION PRESENTED HEREIN HAS BEEN COMPILED FROM SOURCES CONSIDEPED TO BE DEPENDABLE AND IS ACCURATE TO THE BEST OF SELLER'S KNOWLEDGE, HOWEVER, SELLER MAKES NO WARRANTY WHATSOEVER, EXPRESSED, IMPLIED OR OF MERCHANTABILITY REGARDING THE ACCURACY OF SUCH DATA OR THE RESULTS TO BE OBTAINED FROM THE USE THEREOF. SELLER ASSUMES NO RESPONSIBILITY FOR INJURY TO BUYER OR TO THIRD PERSONS OR FOR ANY DAMAGE TO ANY PROPERTY AND BUYER ASSUMES ALL SUCH RISKS."

MATERIAL SAFETY DATA SHEET

NPVLA 6-70

(Approved by U. S. Department of Labor "Essentially Similar" to form LS8-005-4)

Section I

MANUFACTURER'S NAME	THE LUBRIZOL CORPORATION
STREET ADDRESS	29400 Lakeland Blvd.
CITY, STATE, AND ZIP CODE	Wickliffe, Ohio - 44092
EMERGENCY TELEPHONE NO.	Area Code 216, 943-4200
CHEMICAL NAME AND SYNONYMS	TRADE NAME: OS No. 65135-TYPE
CHEMICAL FAMILY	FORMULA

Section II – HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, & SOLVENTS

PIGMENTS	%	TLV (Units)	SOLVENTS	%	TLV (Units)
CATALYST			ADDITIVES		
VEHICLE					

Safety and handling instructions given on our Material Safety Data Sheet are based upon a review of the toxicological properties of the individual components or a review of the properties of a similar composition.

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	TLV (Units)
CAUTION! COMBUSTIBLE!		
Product contains Xylene (Xylene contains <0.1% Benzene)		
Product contains petroleum distillates		
Product contains manganese compound. OSHA TLV		5mg/cm^3
manganese fume (as manganese) OSHA TLV		1mg/cm^3

Section III - PHYSICAL DATA

BOILING POINT (°F.)	Not Determined	SPECIFIC GRAVITY (H_2O=1) @ 15.6°C	1.0
VAPOR PRESSURE (mm Hg.)	Not Determined	PERCENT VOLATILE BY VOLUME (%)	Not Determined
VAPOR DENSITY (AIR=1)	Not Determined	EVAPORATION RATE (.....=1)	Not Determined
SOLUBILITY IN WATER	Insoluble		
APPEARANCE AND ODOR	Dark Colored Liquid		

Section IV – FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (METHOD USED)	40°C (PMCC)	FLAMMABLE LIMITS	LEL	UEL
		Not Determined		
EXTINGUISHING MEDIA	CO_2, dry chemical, foam			
SPECIAL FIRE FIGHTING PROCEDURES	See above			
UNUSUAL FIRE AND EXPLOSION HAZARDS	CAUTION! COMBUSTIBLE! Avoid excessive heat, sparks or open flames.			

Section V - HEALTH HAZARD DATA

RESHOLD LIMIT VALUE
o OSHA exposure standard or threshold limit value has been established for this product.

ECTS OF OVEREXPOSURE
P)roduct is believed to be toxic orally. Product is not believed to a primary skin or eye
rriant. Product may cause nasal and respiratory irritation. Minor irritation may occur
after prolonged or repeated contact with the skin. Avoid such exposure.

MERGENCY AND FIRST AID PROCEDURES
n case of eye contact: Flush thoroughly with plenty of water.
n case of skin contact: Wash thoroughly with soap and water.
or inhalation: Remove to fresh air.

Section VI - REACTIVITY DATA

ABILITY			CONDITIONS TO AVOID
	UNSTABLE		Avoid temperatures greater than 37.8°C.
	STABLE	X	

COMPATABILITY (Materials to avoid)
void strong oxidizing agents.

ZARDOUS DECOMPOSITION PRODUCTS
Thermal decomposition or burning may produce oxides of carbon , nitrogen, copper and
anganese.

ZARDOUS LYMERIZATION			
	MAY OCCUR		CONDITIONS TO AVOID
	WILL NOT OCCUR	X	

Section VII - SPILL OR LEAK PROCEDURES

EPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
andle as an oil spill. Use adequate ventilation - avoid breathing vapors or mists.

ASTE DISPOSAL METHOD
Chemical waste disposal is governed by the Resource Conservation and Recovery Act as
well as by other local, state and federal laws and regulations.

Section VIII - SPECIAL PROTECTION INFORMATION

SPIRATORY PROTECTION (Specify type)

NTILATION			
	LOCAL EXHAUST	X	SPECIAL
	MECHANICAL (General)	X	OTHER

OTECTIVE GLOVES
Plastic or rubber gloves recommended

EYE PROTECTION
Chemical Splash Goggles Recommended

HER PROTECTIVE EQUIPMENT
Above protective devices are recommended to conform with recognized hygienic practices
when handling chemicals.

Section IX - SPECIAL PRECAUTIONS

CAUTIONS TO BE TAKEN IN HANDLING AND STORING
AUTION! COMBUSTIBLE! Store at temperatures below 37.8°C. Store in a cool, dry area
n tightly closed containers. Avoid excessive heat, sparks or open flames. Normal

HER PRECAUTIONS
ygienic and safety precautions should be observed when handling chemicals. Avoid
rolonged or repeated contact with the skin. Wash with soap and water after handling.
se adequate ventilation - avoid breathing vapors or mists.

APPENDIX II

CYCLE ANALYSES

TABLE 5

ANALYSIS OF MTU LHD CYCLE (DEC 5 1986)

LINEAR REGRESSION ANALYSIS - USING LEAST SQUARES METHOD
(USING HP INPUT AS REFERENCE(X) AND OBSERVED VALUES AS ACTUAL(Y))

SPEED ANALYSIS		EPA CRITERIA
SLOPE	1.009	.970-1.03
Y INTERCEPT	-21 RPM	+- 50 RPM
STANDARD ERROR OF ESTIMATE	56 RPM	100 RPM
COEFFICIENT OF DETERMINATION	0.9753	> .970

TORQUE ANALYSIS		EPA CRITERIA
SLOPE	0.978	0.83-1.03
Y INTERCEPT	7.0 N.m	+- 20 N.m
STANDARD ERROR OF ESTIMATE	7.1 N.m	13 % OF MAX TORQUE (690 N.m)
COEFFICIENT OF DETERMINATION	0.9973	> .880

POWER ANALYSIS		EPA CRITERIA
SLOPE	0.964	.890-1.03
Y INTERCEPT	2.4 kW	+- 3.8 kW
STANDARD ERROR OF ESTIMATE	3.2 kW	8 % OF MAX POWER (138 kW)
COEFFICIENT OF DETERMINATION	0.9848	> .910

ACTUAL INTEGRATED CYCLE POWER	70.1 kW	
REFERENCE INTEGRATED CYCLE POWER	70.1 kW	EPA CRITERIA
PERCENT DIFFERENCE	-0.1%	(-15% TO +5%)

TABLE 6

ANALYSIS OF MTU MOD 5 LHD CYCLE (FEB 2 1986)

LINEAR REGRESSION ANALYSIS - USING LEAST SQUARES METHOD
(USING HP INPUT AS REFERENCE(X) AND OBSERVED VALUES AS ACTUAL(Y))

SPEED ANALYSIS		EPA CRITERIA
SLOPE	1.044	.970-1.03
Y INTERCEPT	-111 RPM	+- 50 RPM
STANDARD ERROR OF ESTIMATE	62 RPM	100 RPM
COEFFICIENT OF DETERMINATION	0.9167	> .970

TORQUE ANALYSIS		EPA CRITERIA
SLOPE	1.012	0.83-1.03
Y INTERCEPT	-0.4 N.m	+- 20 N.m
STANDARD ERROR OF ESTIMATE	6.6 N.m	13 % OF MAX TORQUE (690 N.m)
COEFFICIENT OF DETERMINATION	0.9975	> .880

POWER ANALYSIS		EPA CRITERIA
SLOPE	0.965	.890-1.03
Y INTERCEPT	3.2 kW	+- 3.8 kW
STANDARD ERROR OF ESTIMATE	3.9 kW	8 % OF MAX POWER (138 kW)
COEFFICIENT OF DETERMINATION	0.9697	> .910

ACTUAL INTEGRATED CYCLE POWER	94.7 kW	
REFERENCE INTERGRATED CYCLE POWER	94.8 kW	EPA CRITERIA
PERCENT DIFFERENCE	-0.1%	(-15% TO +5%)

TRANSIENT CYCLE ANALYSIS AND VALIDATION

This analysis procedure is that used by EPA for validating its Heavy Duty Diesel Engines dynamometer schedule. The description of the validation criteria can be found in the Federal Register Vol. 45, No. 14, Monday, January 21, 1980, pages 4210-4211. Tolerances as defined by EPA are shown in the following table.

Regression Line Tolerances

	Speed	Torque	Brake HP.
Standard Error of Estimate (SE) of y on x	100 rpm	13% of max. Engine Torque	8% of max. Brake HP.
Slope of the Regression Line, M	0.970-1.030	.83-1.03 Hot .77-1.03 Cold	.89-1.03 (Hot) .87-1.03 (Cold)
Coefficient of Determination R^2	.9700*	.8800 Hot* .8500 Cold*	.9100*
Y Intercept of the Regression Line B	$\pm$ 50 rpm	-15 ft.lb.	$+$ - 5.0 of Brake HP.

* minimum.

Also, the integrated brake horsepower must be within -15 percent and+5 percent of the integrated reference brake horsepower.

The following table describes conditions at which points can be deleted from the regression analysis. These do not readily apply to our current cycles.

PERMITTED POINT DELETIONS FROM REGRESSION ANALYSIS

Condition		Points to be Deleted
First 24 seconds ($\pm$ 1) of free idle of hot and cold cycles		Speed, torque, brake horsepower.
Wide Open Throttle	(speed control:) (torque feedback < torque reference)	torque, brake horsepower
	(torque control:) (speed feedback < speed reference)	speed, brake horsepower
Speed control closed throttle. Torque reference < zero		torque brake horsepower
Gasoline fueled engines equipped with automatic chokes: first 150 seconds of cold cycle or first 30 seconds of hot cycle, closed throttle and: manual transmission, if torque feedback		
A: is equal to zero ($\pm$ 10 ft.lbs.) or:		speed brake horsepower
B: automatic transmission, if torque feedback is equal to curb idle transmission torque ($\pm$10 ft.lbs.).		speed brake horsepower

The Federal Register states that the actual observed speed and torque values may be shifted a maximum of $\pm$ 5 seconds to reduce error, as long as speed and torque are both shifted the same amount. Calculations should be to five significant figures.

To perform the linear regression analysis, the actual value (y) is plotted against the reference value (x) for speed, torque and brake horsepower. The method of least squares is used to determine a best fit curve in the form $y = mx + b$ where

- y = actual values of speed, torque and horsepower
- m = slope of regression line
- x = reference value of speed, torque and horsepower
- b = the y intercept of the regression line.

Transient Cycle Analysis and Validation.

The slope and y intercept are calculated using the following equations:

$$m = \frac{\overline{XY} - \bar{X}\bar{Y}}{\overline{X^2} - (\bar{X})^2}$$

$$b = \bar{Y} - m\bar{X}$$

Standard error of estimate (SE) of y or x and the coefficient of determination r^2 shall be calculated for each regression line using the following equations:

$$SE = \left(\frac{\Sigma (Yi - Y\,est(i))^2}{N} \right)^{\frac{1}{2}} \text{ where } Y\,est(i) = mx_i + b$$

$$r^2 = \frac{\Sigma (Y\,est(i) - \bar{Y})^2}{\Sigma (Y - \bar{Y})^2}.$$

APPENDIX II

The following figures illustrate, second-by-second, the comparison between the requested and actual engine speed and torque during the MTU and MTU MOD 5.

FIGURE 18: TORQUE (MTU LHD CYCLE)

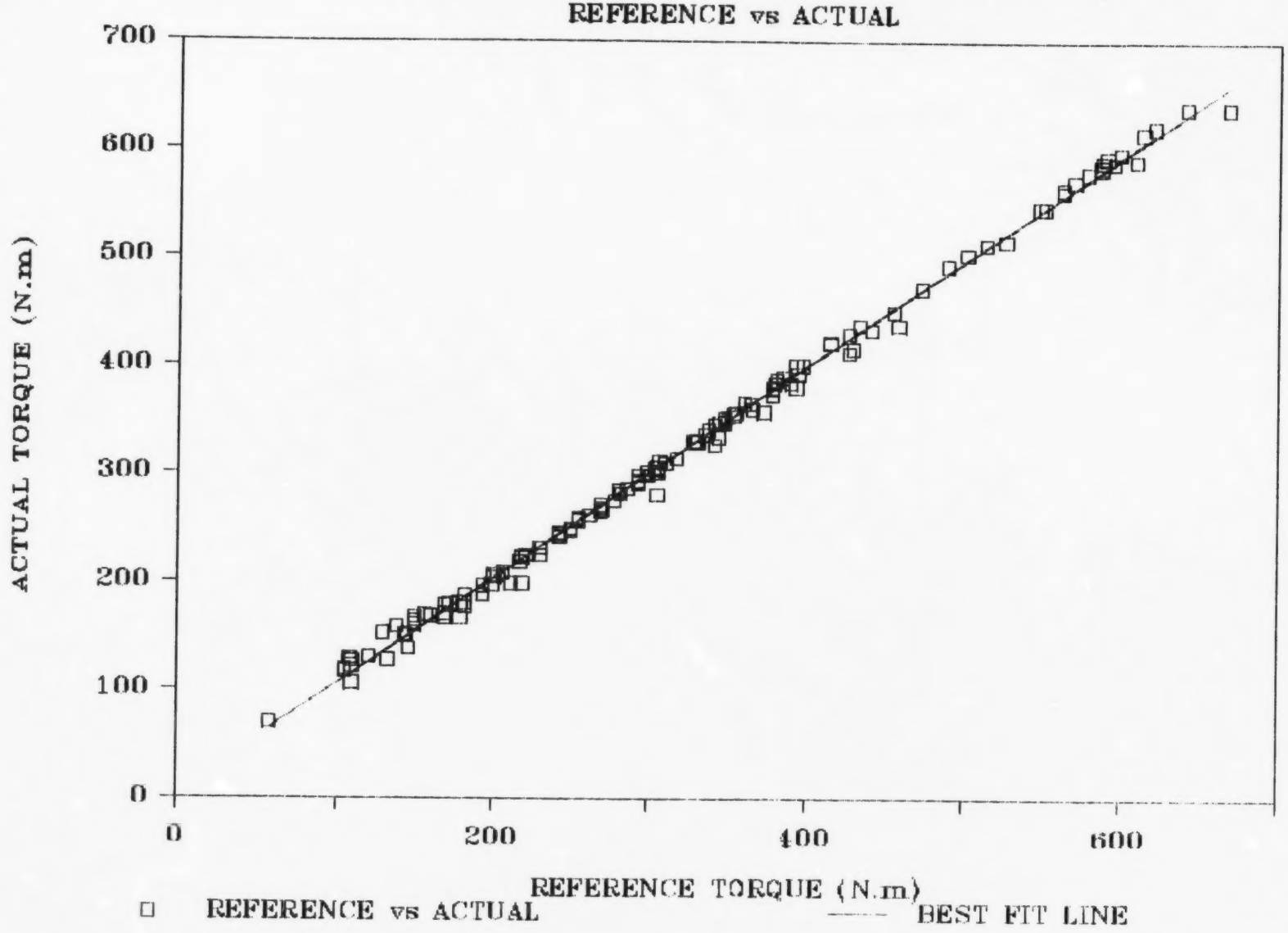


FIGURE 19: SPEED (MTU LHD CYCLE)

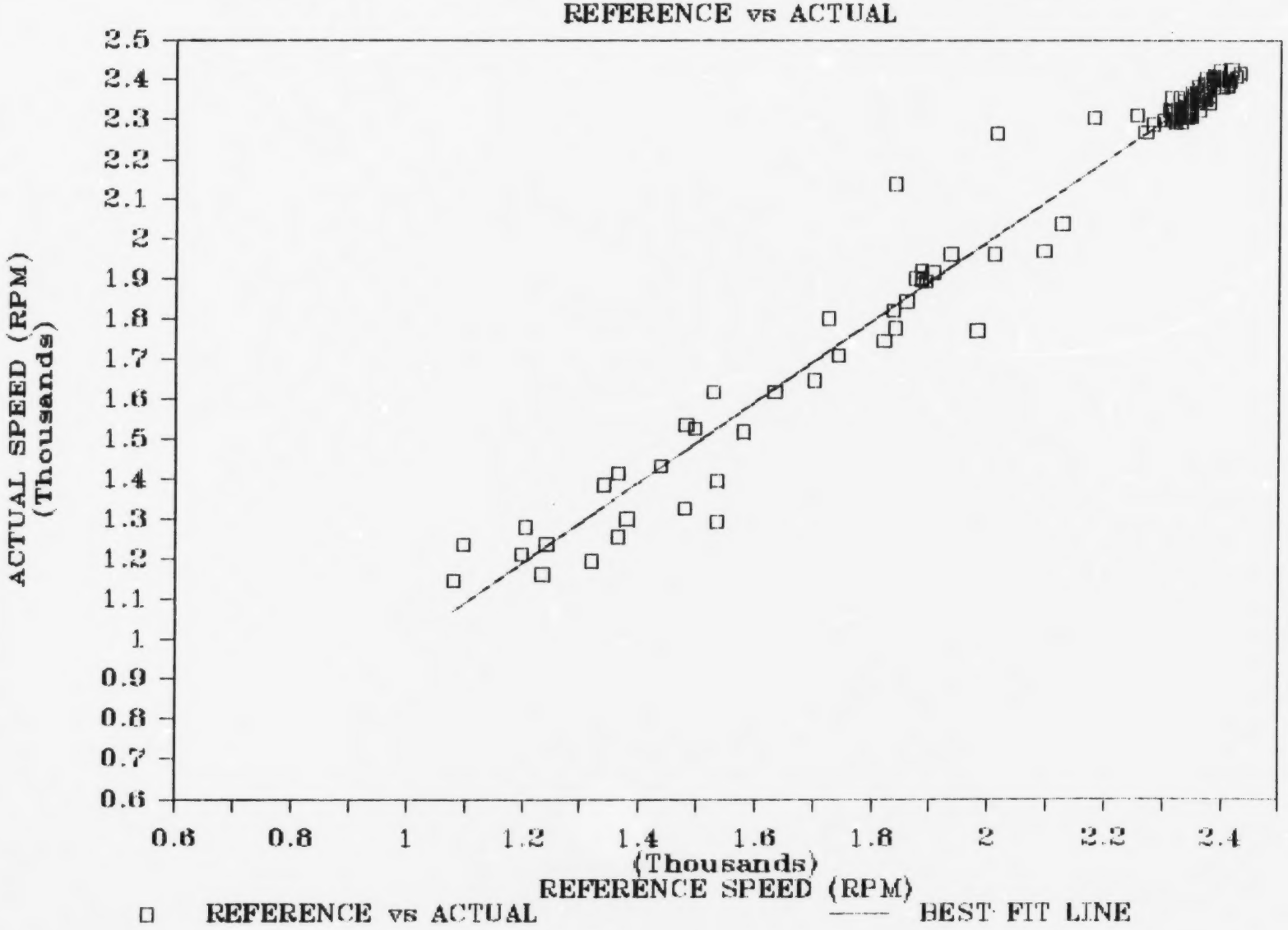


FIGURE 20: POWER (MTU LHD CYCLE)

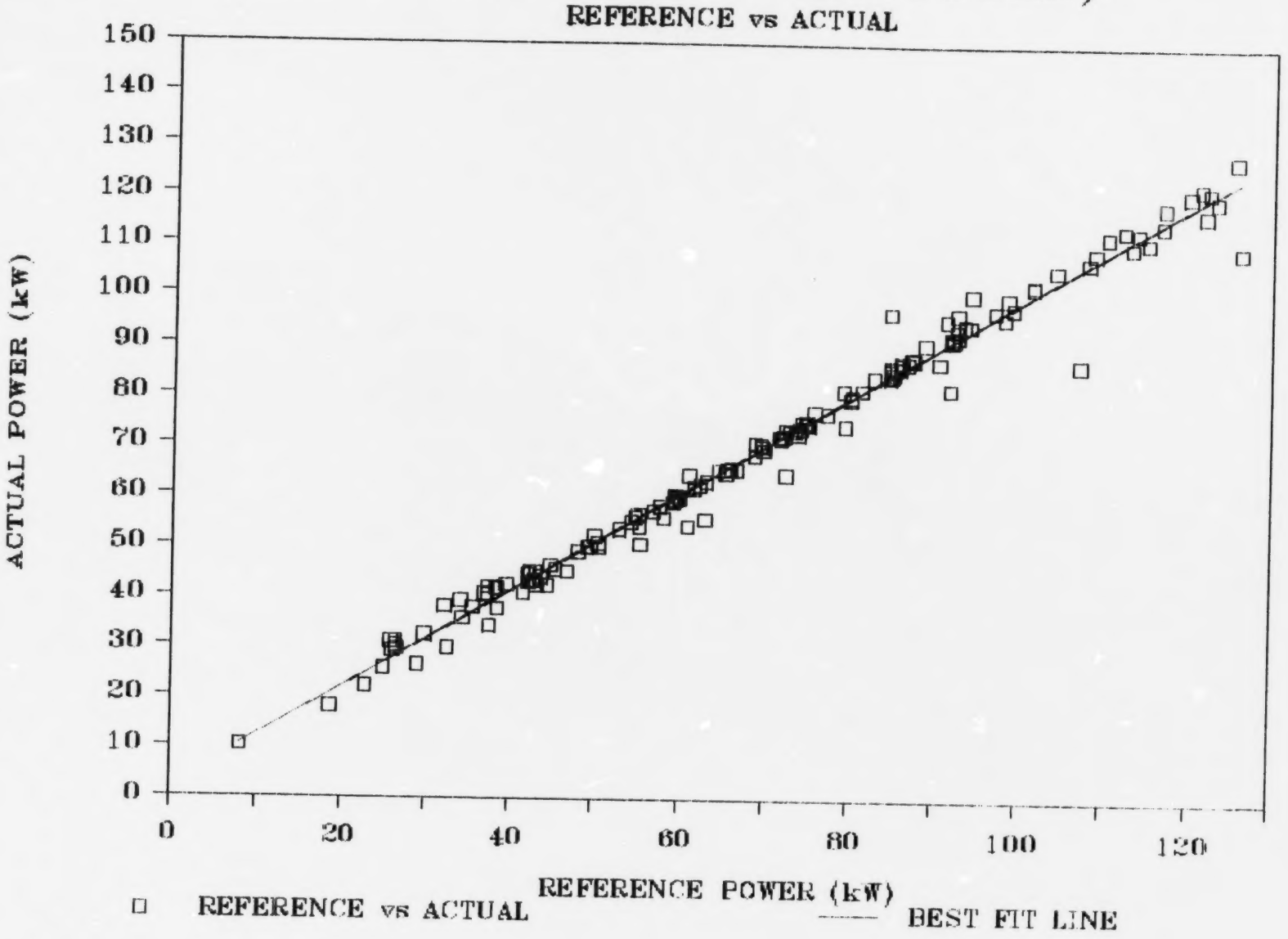


FIGURE 21:

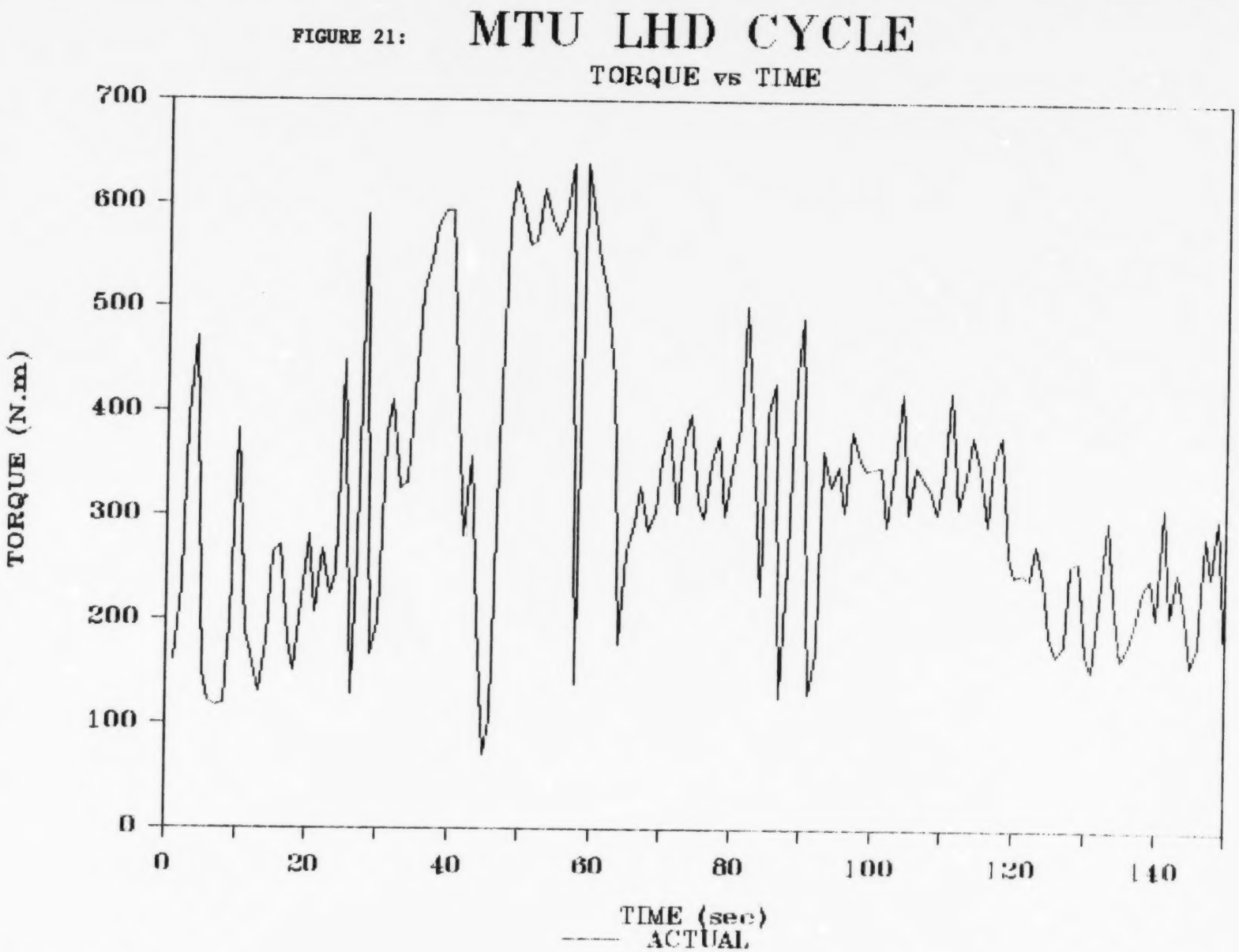

MTU LHD CYCLE
TORQUE vs TIME
TORQUE (N.m)
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
TIME (sec)
ACTUAL

FIGURE 22: MTU LHD CYCLE

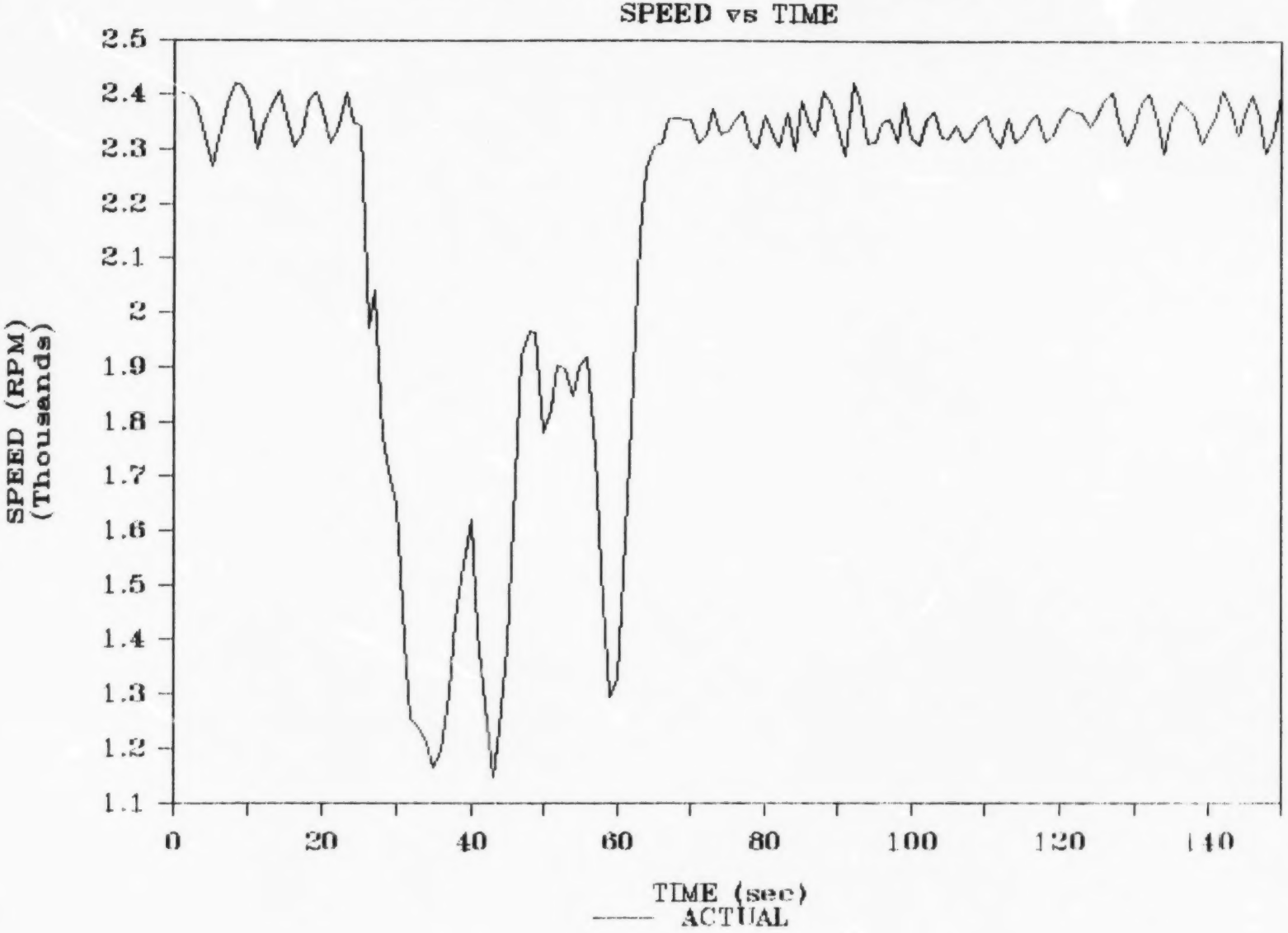


FIGURE 23:

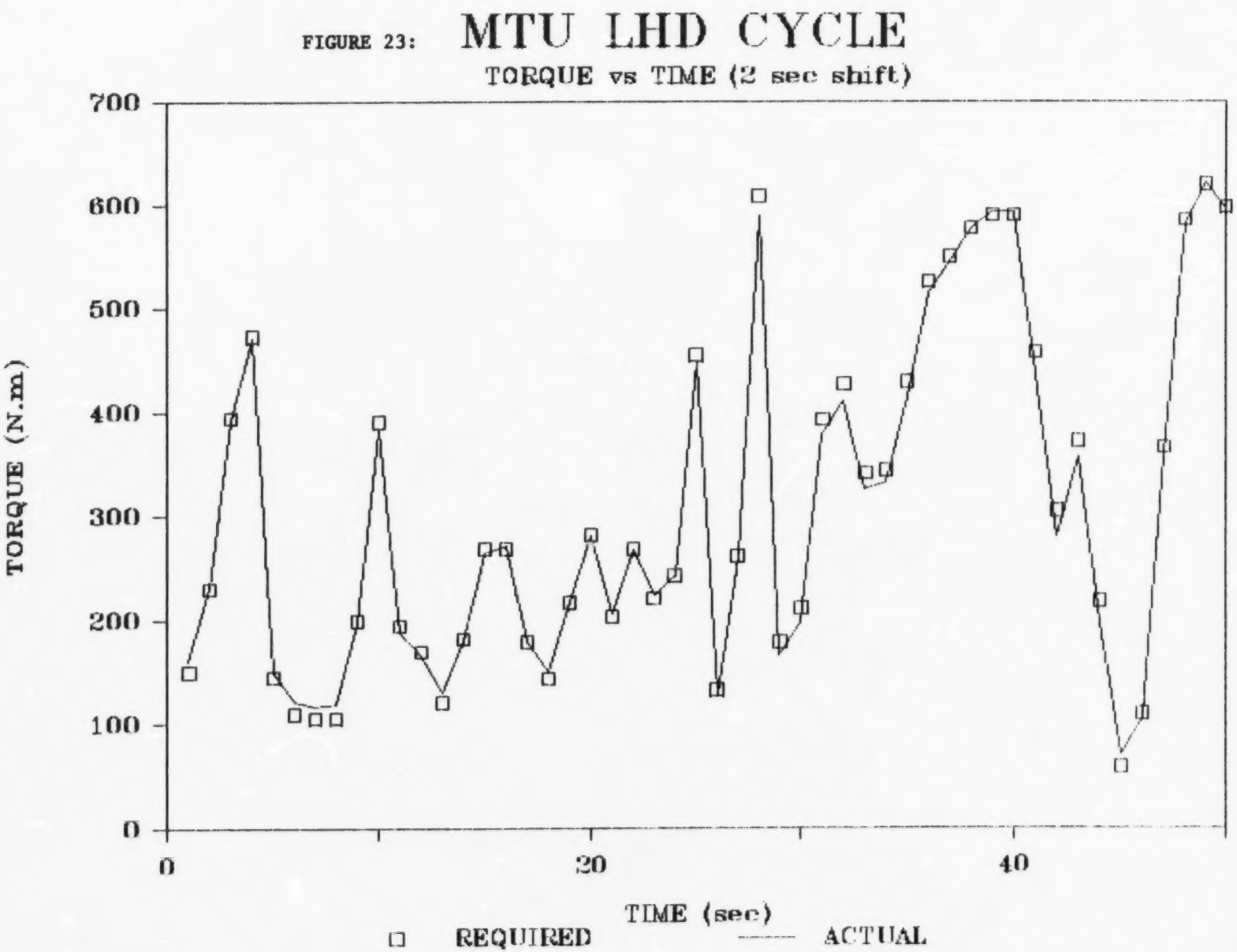

MTU LHD CYCLE
TORQUE vs TIME (2 sec shift)
700
600
500
400
300
200
100
0
TORQUE (N.m)
0
20
40
TIME (sec)
REQUIRED
ACTUAL

FIGURE 24: MTU LHD CYCLE

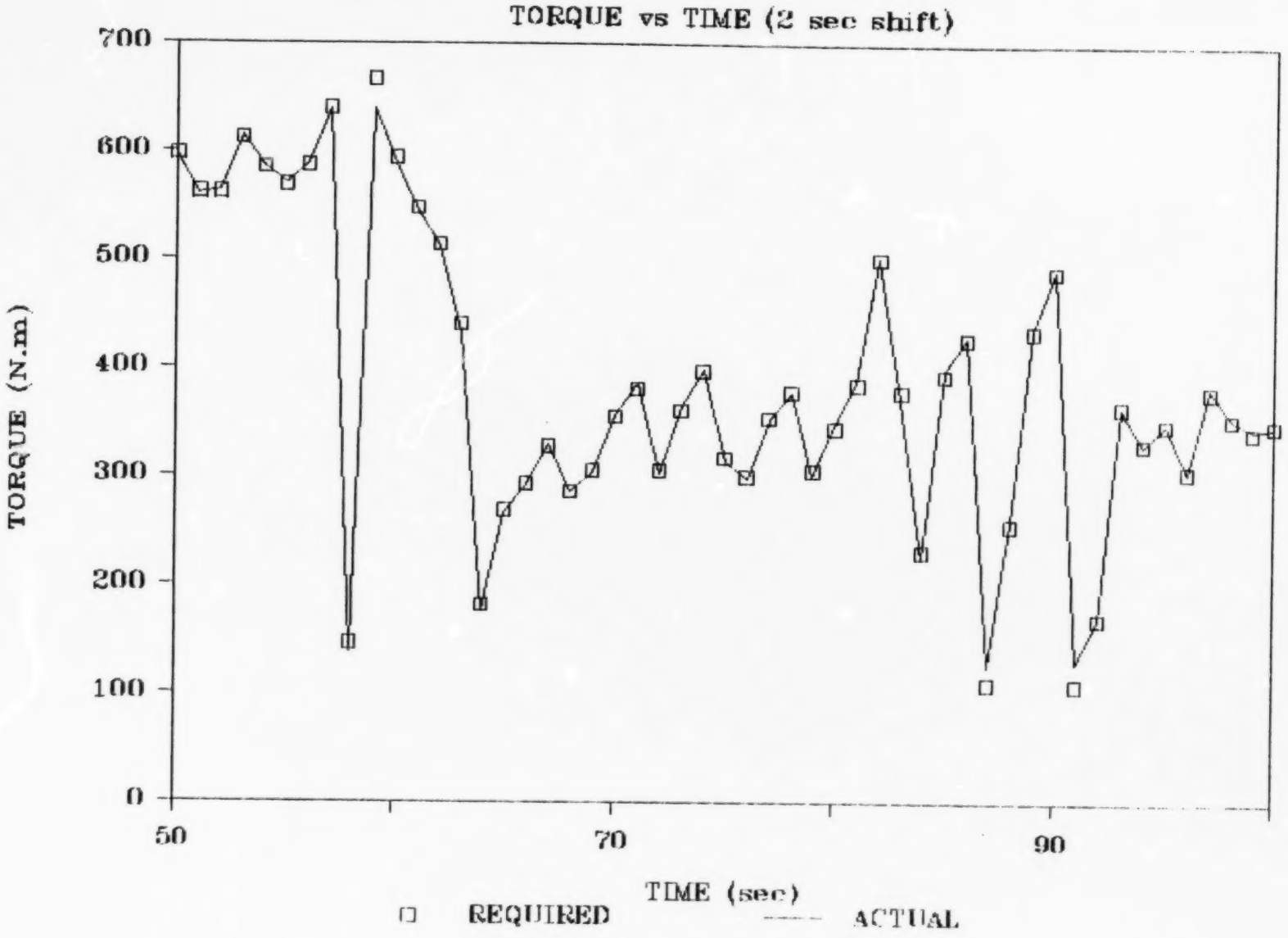


FIGURE 25:

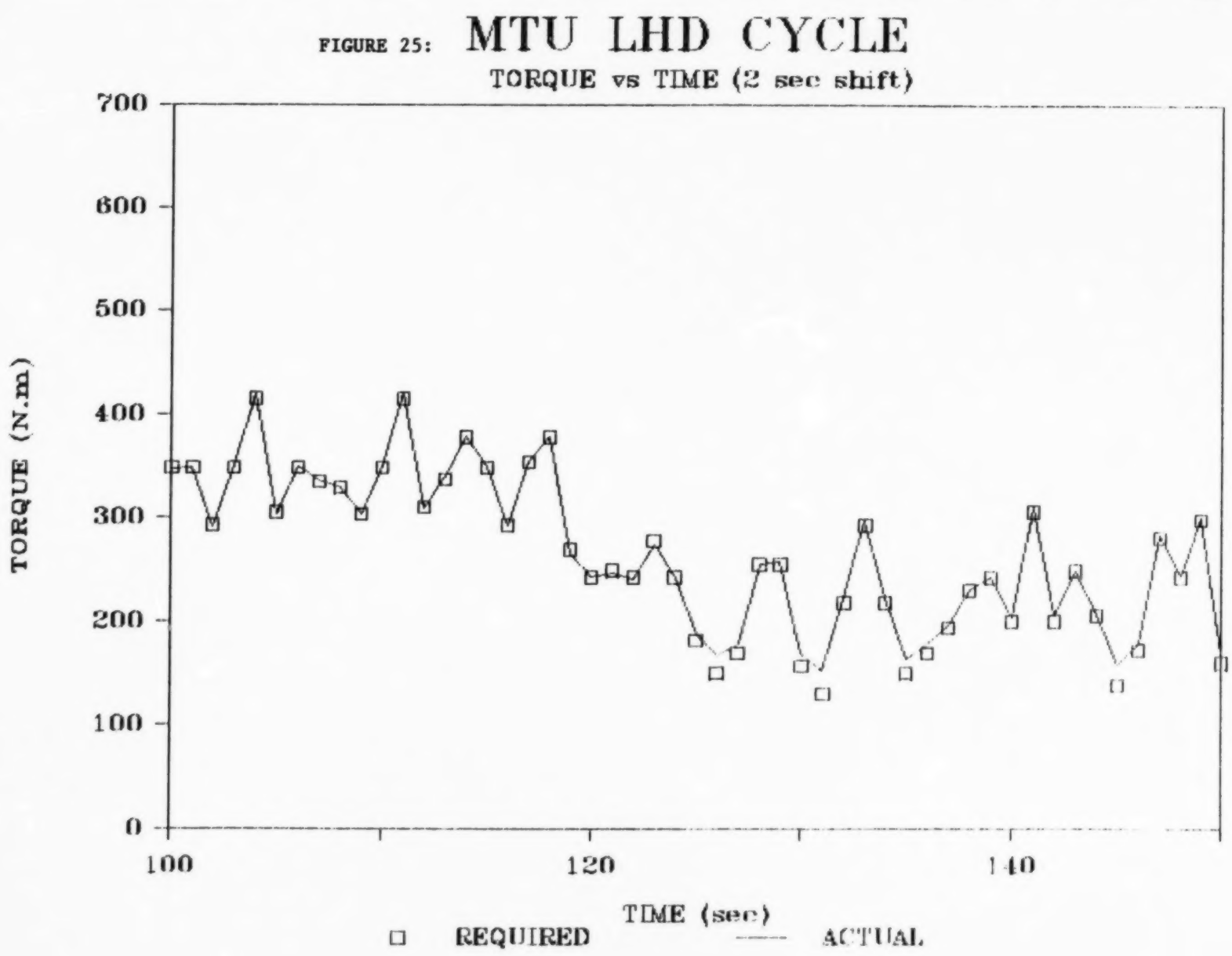

MTU LHD CYCLE
TORQUE vs TIME (2 sec shift)
700
600
500
400
300
200
100
0
TORQUE (N.m)
100
120
140
TIME (sec)
REQUIRED
ACTUAL

FIGURE 26:

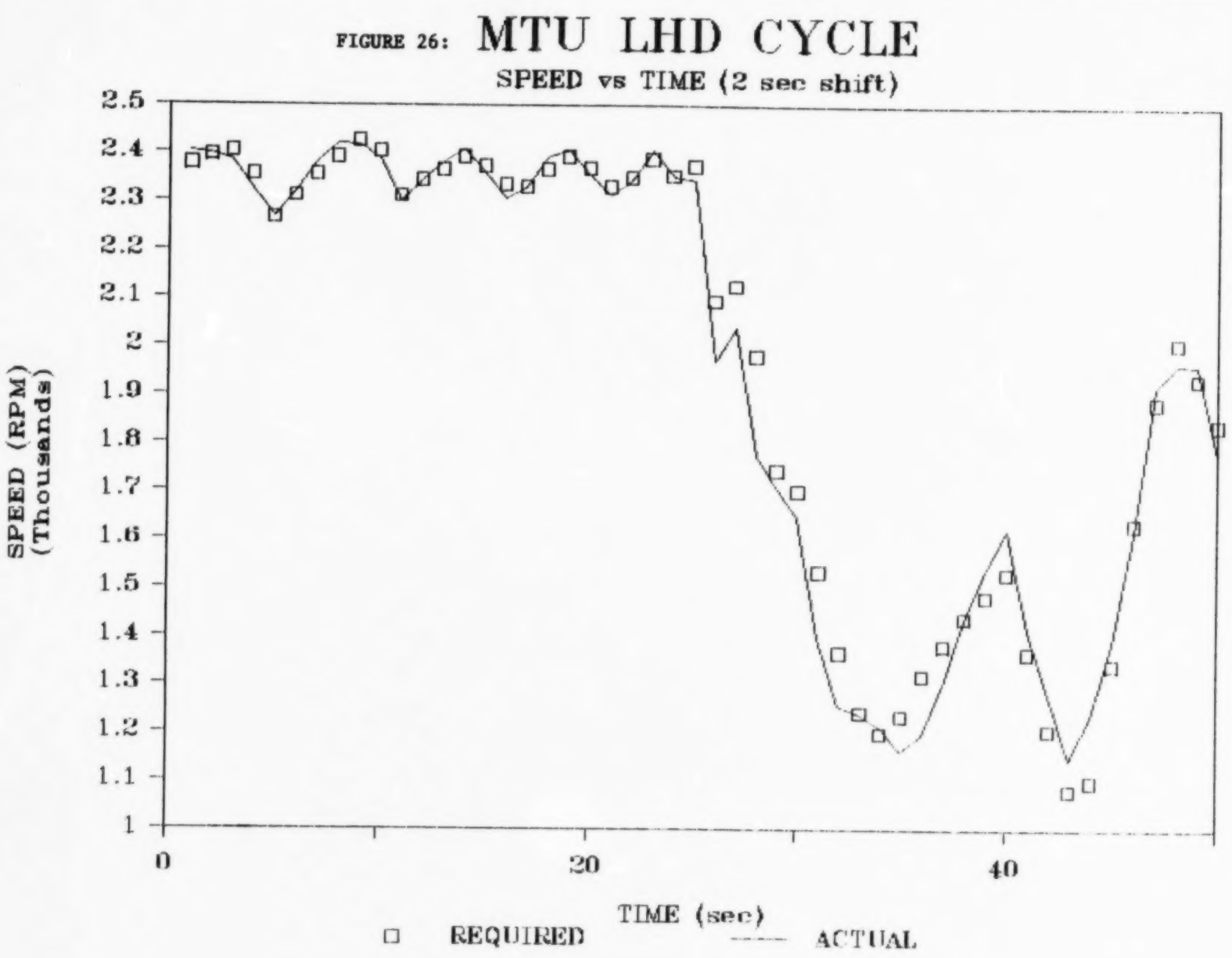

MTU LHD CYCLE
SPEED vs TIME (2 sec shift)
SPEED (RPM)
(Thousands)
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0
20
40
TIME (sec)
REQUIRED
ACTUAL

FIGURE 27:

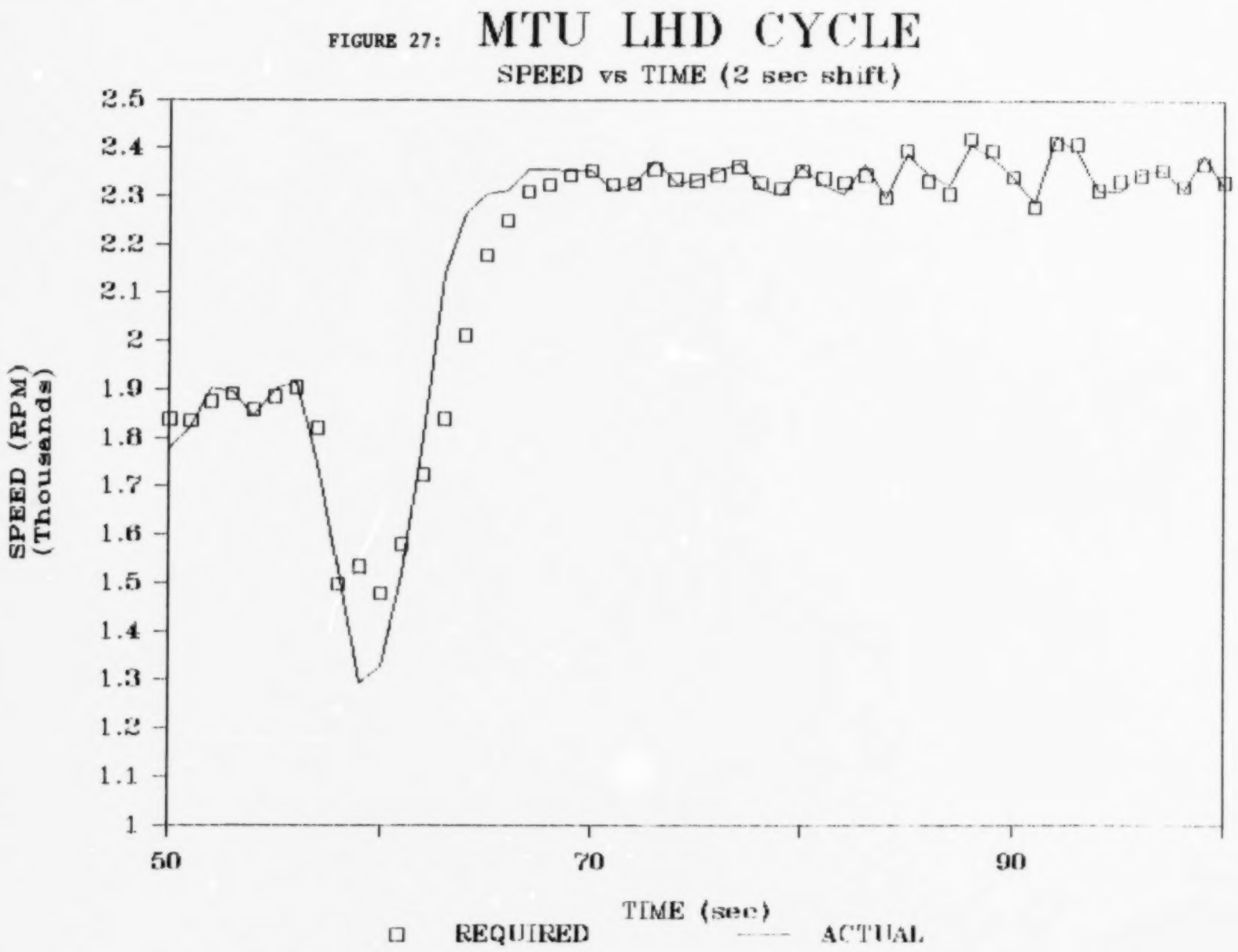

MTU LHD CYCLE
SPEED vs TIME (2 sec shift)
SPEED (RPM)
(Thousands)
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
50
70
90
TIME (sec)
REQUIRED
ACTUAL

FIGURE 28: MTU LHD CYCLE

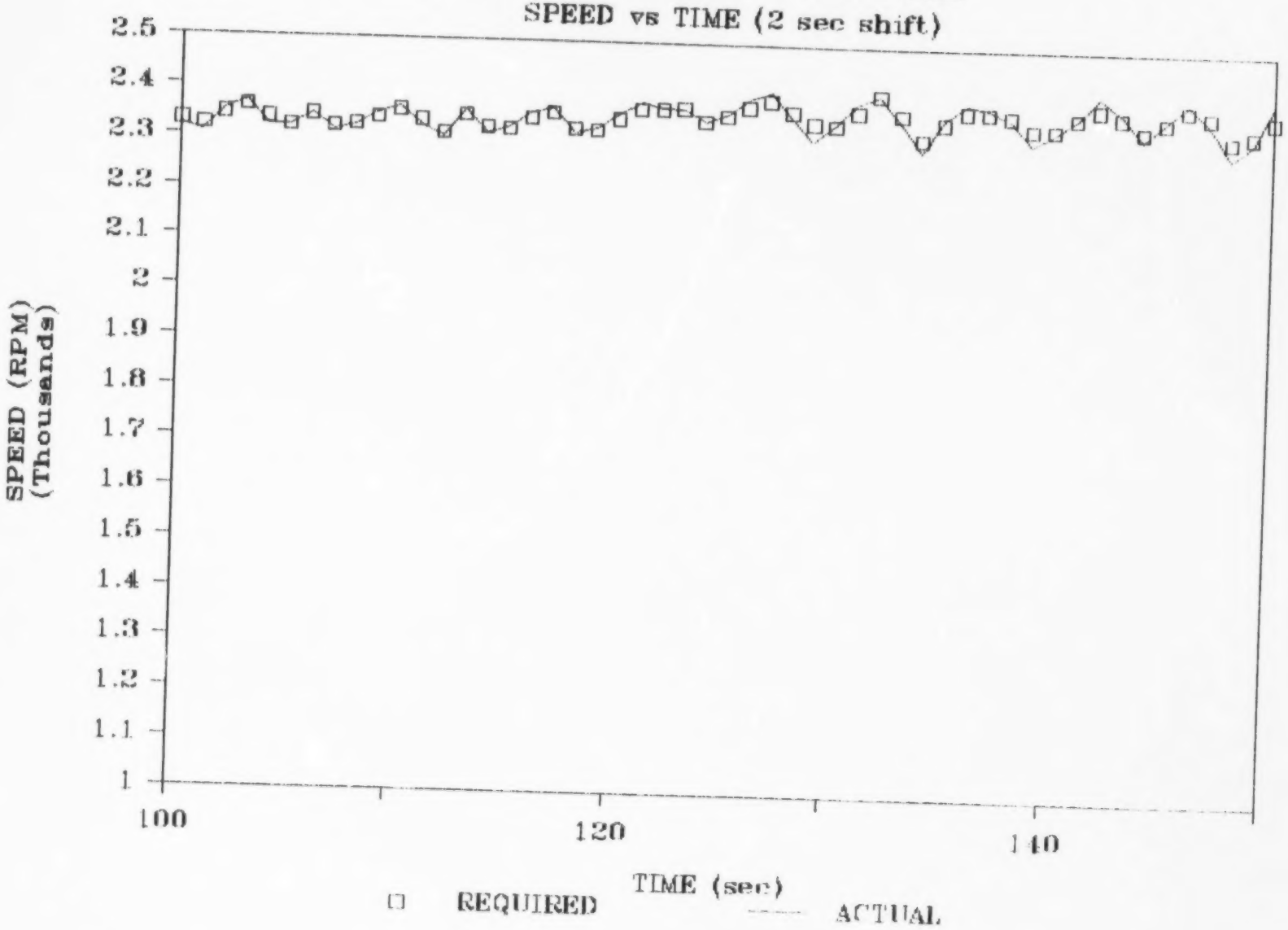


FIGURE 25

TORQUE (MTU MOD 5 LHD CYCLE)

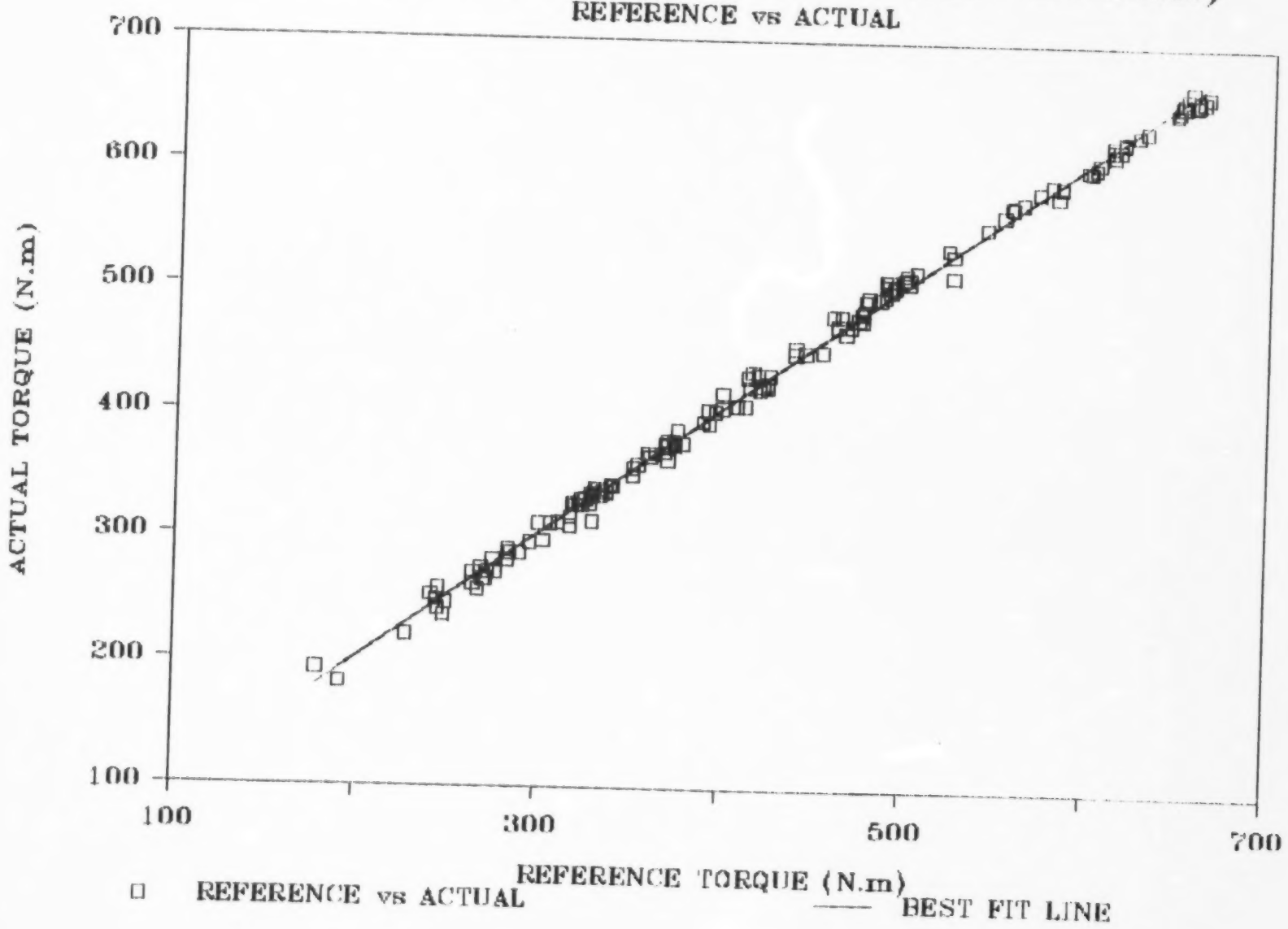


FIGURE 50

SPEED (MTU MOD 5 LHD CYCLE)

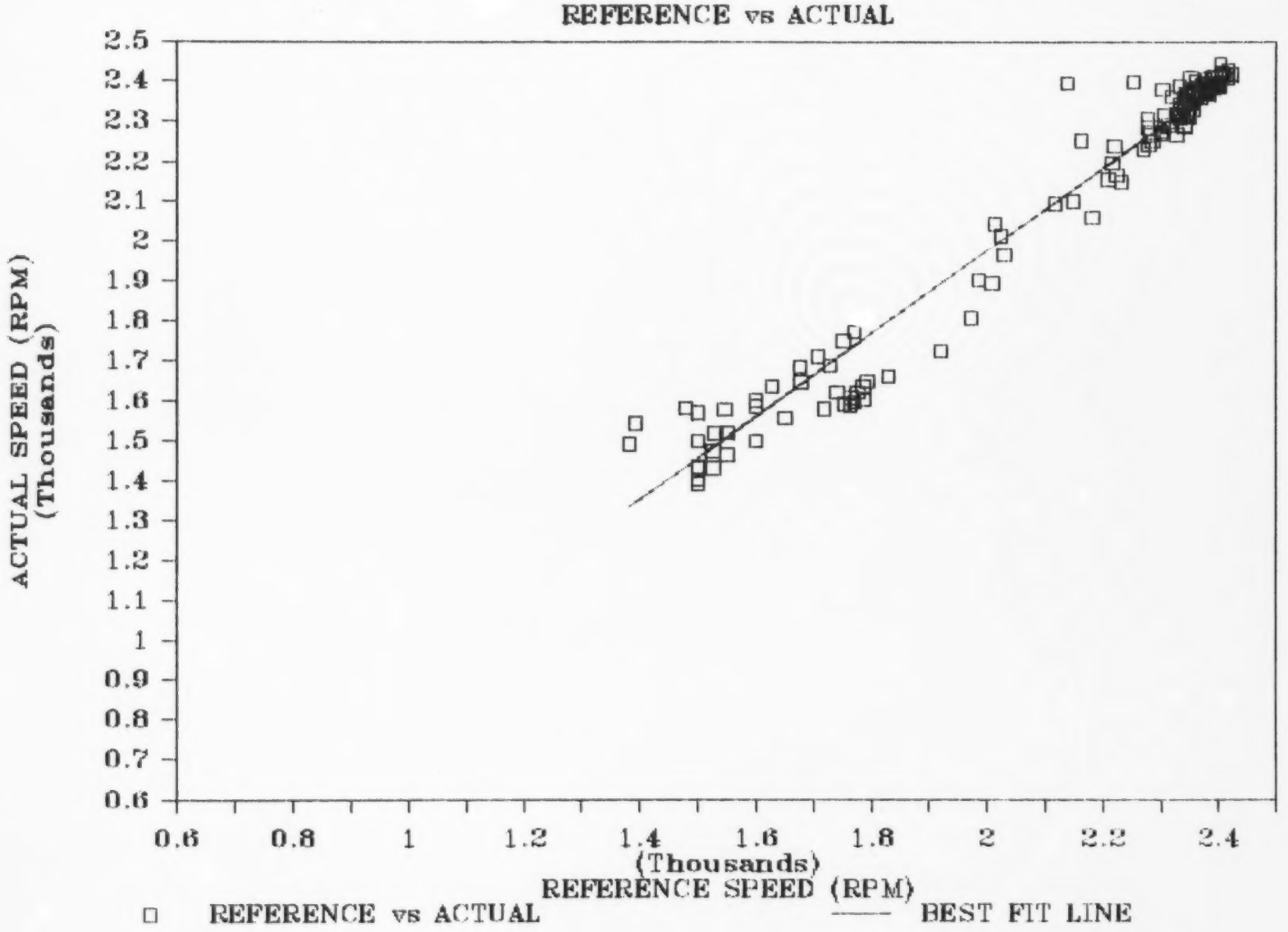


FIGURE 31

POWER (MTU MOD 5 LHD CYCLE)

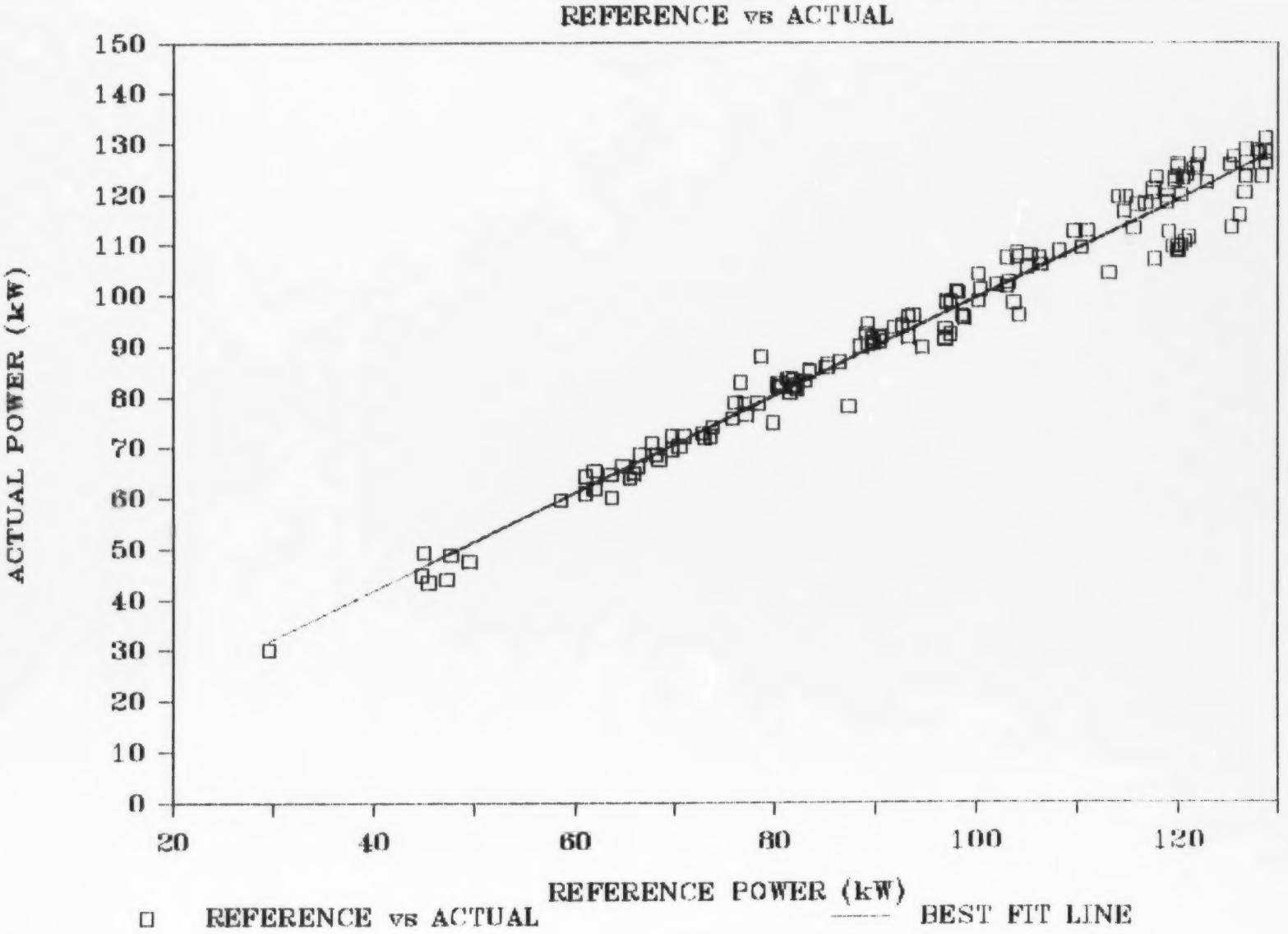


FIGURE 32

MTU MOD 5 LHD CYCLE

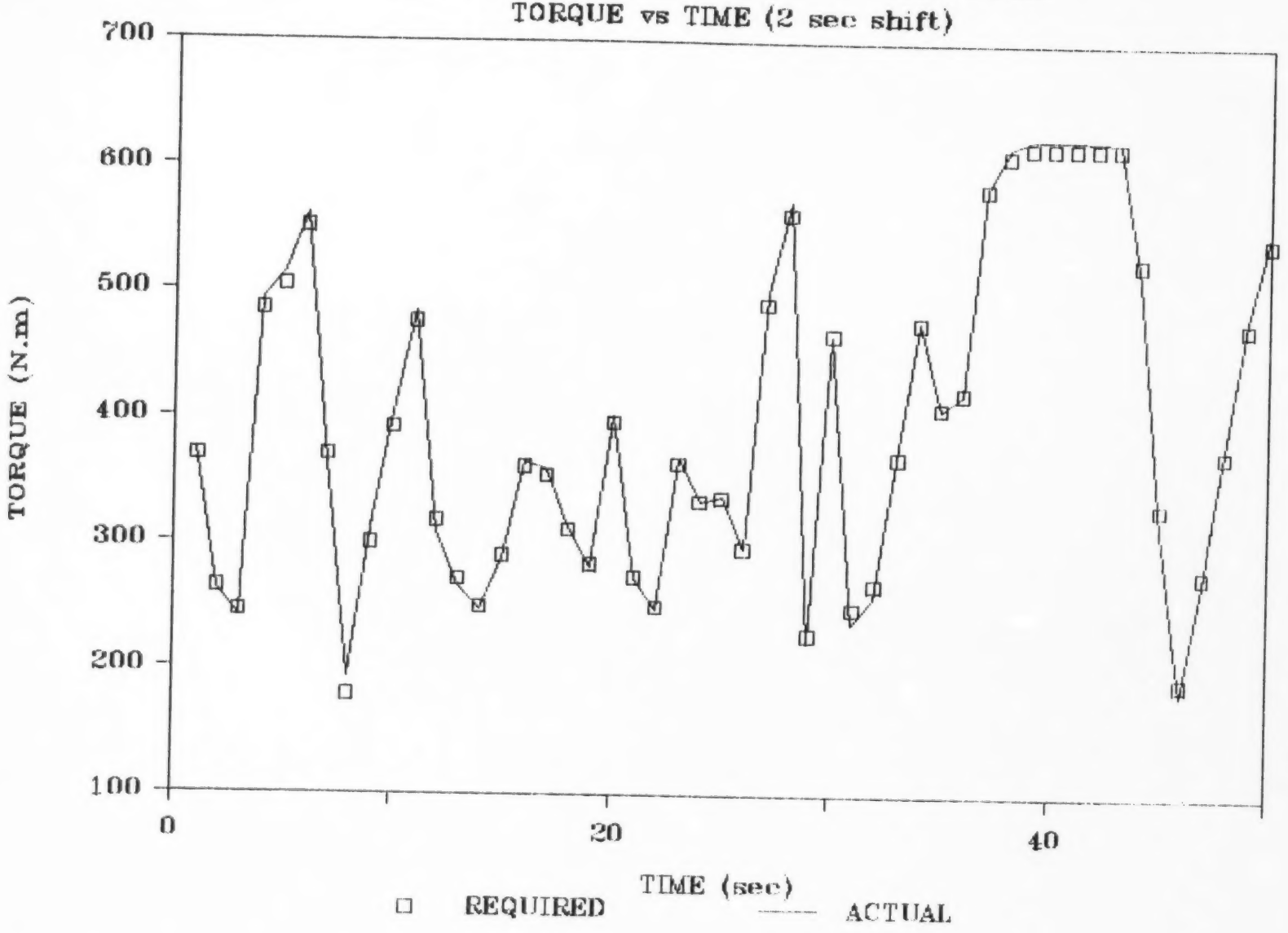


FIGURE 33

MTU MOD 5 LHD CYCLE

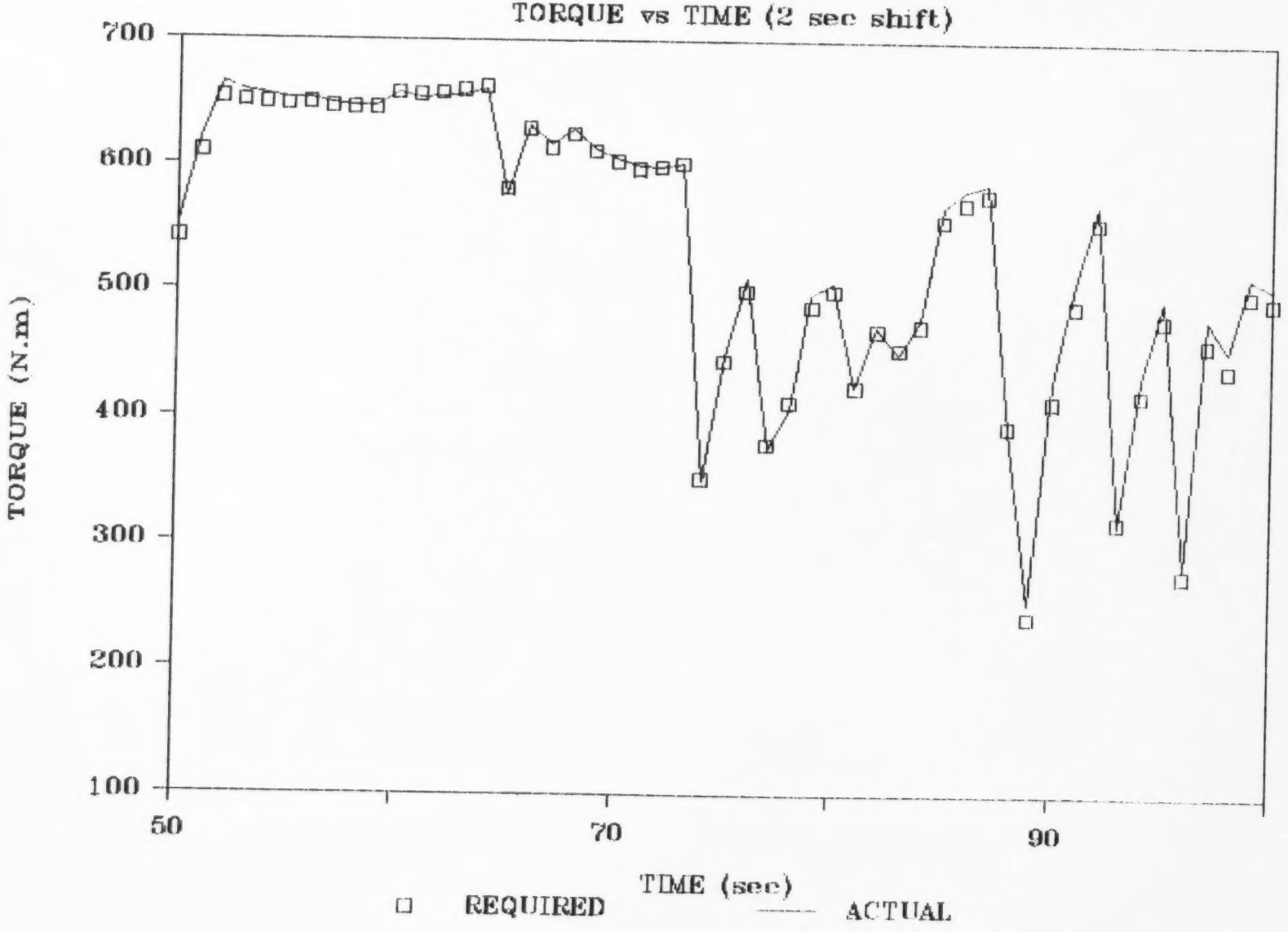


FIGURE 34

MTU MOD 5 LHD CYCLE

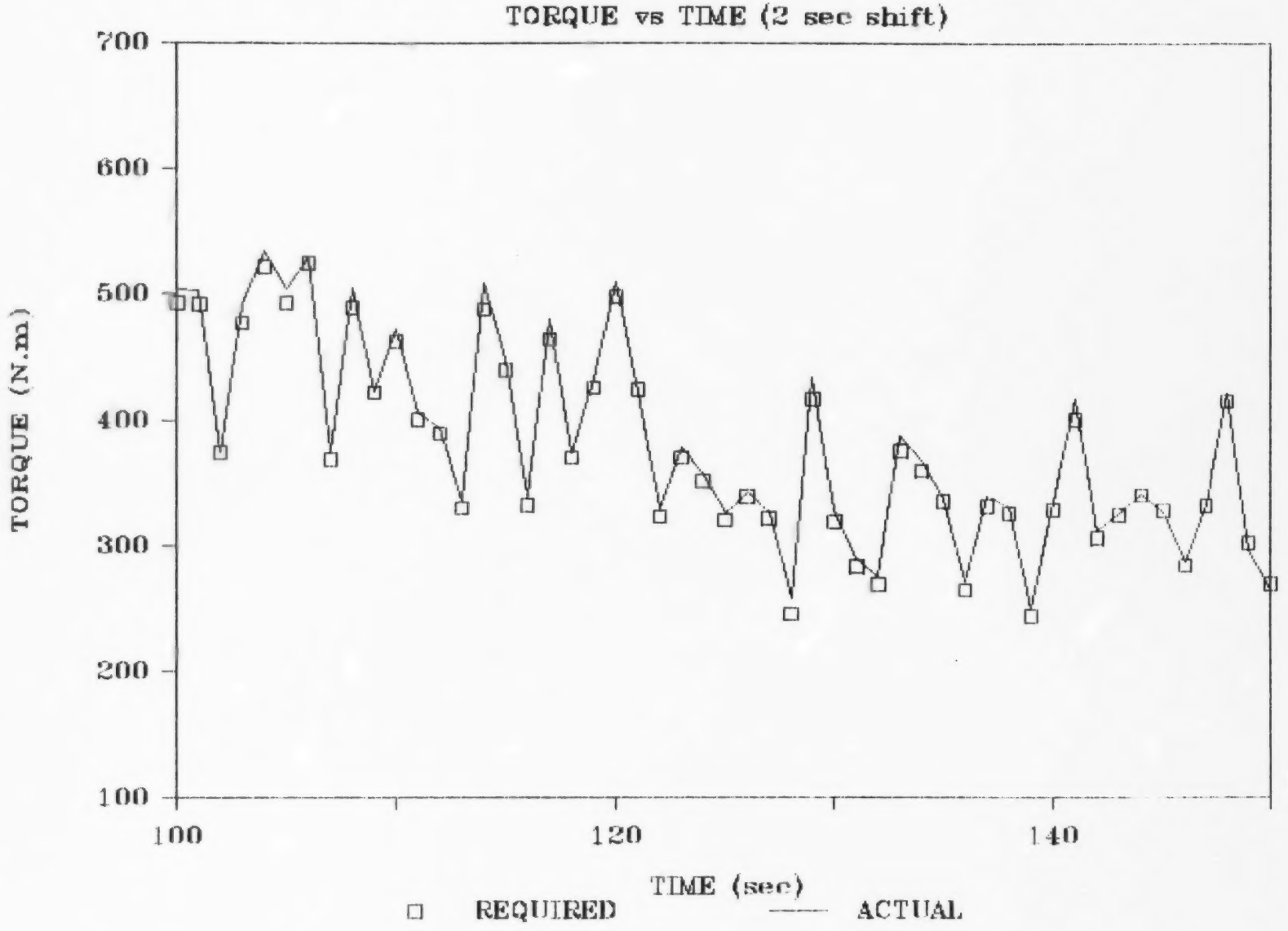


FIGURE 35

MTU MOD 5 LHD CYCLE

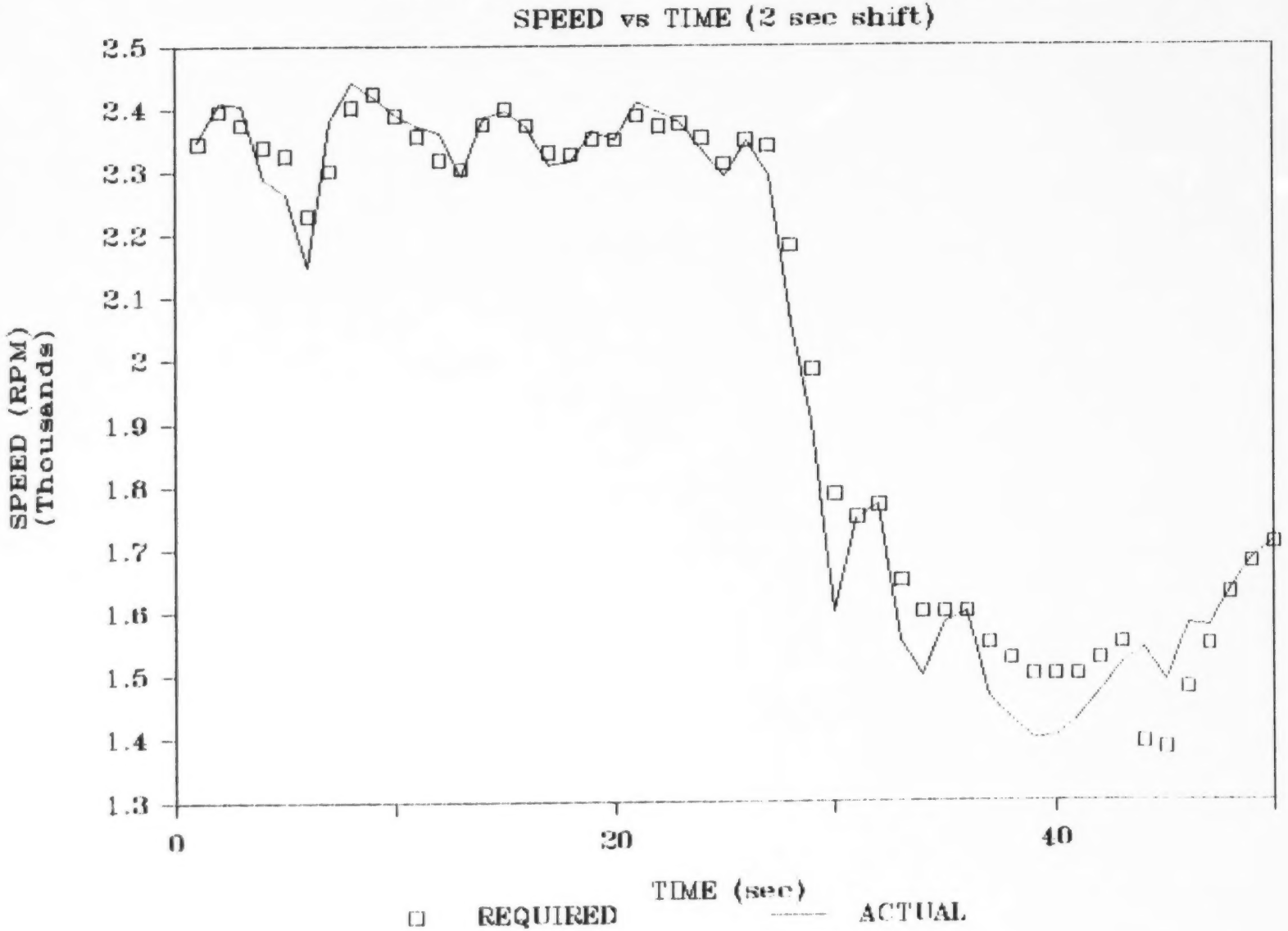


FIGURE 36

MTU MOD 5 LHD CYCLE

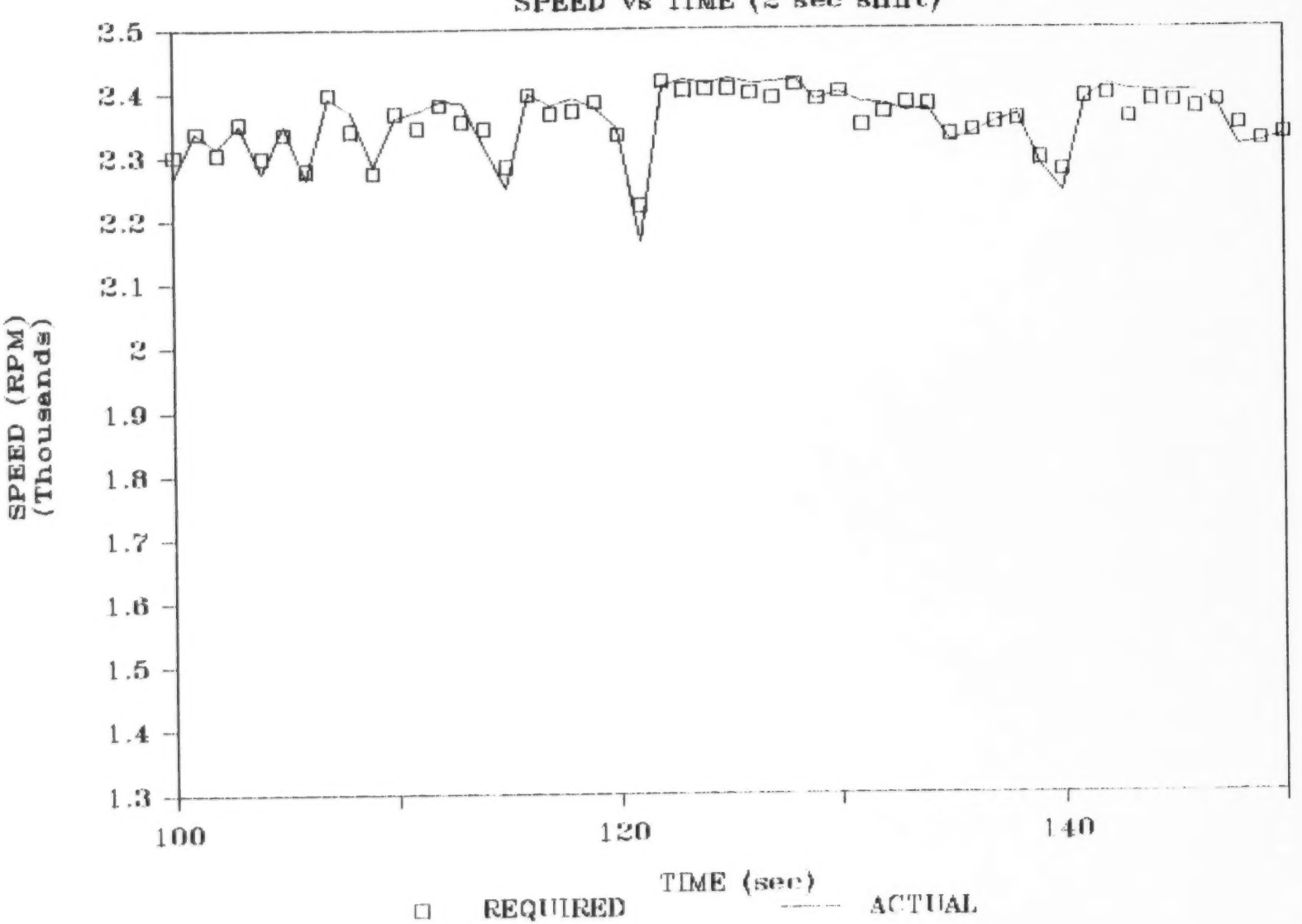


FIGURE 37

MTU MOD 5 LHD CYCLE